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Characterization of Contaminated Nuclear Sites, Facilities and Materials: Radioisotope and Radiopharmaceutical Manufacturers and Suppliers

Evaluation Research Corp.
Oak Ridge, TN

Prepared for

Environmental Protection Agency
Washington, DC

1983

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FINAL REPORT

CHARACTERIZATION OF CONTAMINATED NUCLEAR SITES, FACILITIES AND MATERIALS

(Radioisotope and Radiopharmaceutical Manufacturers and Suppliers)

February 1983

Prepared for:

U.S. Environmental Protection Agency
Washington, D.C.

Prepared by:

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The Environmental Protection Agency (EPA) is developing environmental protection standards for evaluating the risks and characterizing problems associated with disposal of radioactive wastes arising from decontamination and decommissioning D&D operations. Information on operations conducted at sites authorized to possess radioactive materials for the production and/or distribution of radioisotopes and radiopharmaceuticals was compiled and evaluated. This information was used to project the types, nature, and volumes of wastes which are likely be generated during decontamination and decommissioning at representative facilities and identifying special problems that may occur. Radioisotope and radiopharmaceutical manufacturers have been grouped together because decommissioning operations will be similar. Nuclear pharmacies were also evaluated because of their increasing numbers and their role as middlemen between manufacturers and users of radiopharmaceuticals. The majority of the radioactive waste will arise from the decontamination of the laboratories, rather than the disposal of components. The volume of radioactive waste generated by the decontamination and decommissioning of radioisotope and radiopharmaceutical manufacturers and suppliers is projected to range from 32000-92000 m^3. This is a small volumen of radioactive waste compared to volumes arising from other decommissioning activities.

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ABSTRACT

The Environmental Protection Agency (EPA) is developing environmental protection standards for evaluating the risks and characterizing problems associated with disposal of radioactive wastes arising from decontamination and decommissioning (D&D) operations. Information on operations conducted at sites authorized to possess radioactive materials for the production and/or distribution of radioisotopes and radiopharmaceuticals was compiled and evaluated. This information was used to project the types, nature, and volumes of wastes which are likely be generated during decontamination and decommissioning at representative facilities and identifying special problems that may occur.

Radioisotope and radiopharmaceutical manufacturers have been grouped together because decommissioning operations will be similar. Nuclear pharmacies were also evaluated because of their increasing numbers and their role as middlemen between manufacturers and users of radiopharmaceuticals.

The typical manufacturer of radioisotopic materials will have more than one laboratory within a facility. However, in most cases, specific laboratories or pieces of equipment will be decommissioned rather than entire facilities. Therefore representative laboratories used to process the most common radionuclides (^{3}H labeled compounds, ^{14}C labeled compounds, $^{125,131}I$ labeled compounds, ^{137}Cs sealed sources, ^{241}Am sealed sources) and nuclear pharmacy laboratories have been studied and characterized separately for this report.

- The projected volume of radioactive waste for the reference laboratory handling ^{3}H is 29-61 m^3.
- The projected volume of radioactive waste for the reference laboratory handling ^{14}C is 23-43 m^3.
- The projected volume of radioactive waste for the reference laboratory handling radioiodine is 18-29 m^3.

- The projected volume of radioactive waste for the reference laboratory handling ^{137}Cs is 16-28 m^3.

- The projected volume of radioactive waste for the reference laboratory handling ^{241}Am is 17-22 m^3.

The predominant radioisotopes common to most nuclear pharmacies have short half-lives and no significant volumes of waste are projected.

The majority of the radioactive waste will arise from the decontamination of the laboratories, rather than the disposal of components. The volume of radioactive waste generated by the decontamination and decommissioning of radioisotope and radiopharmaceutical manufacturers and suppliers is projected to range from 32000-92000 m^3. This is a small volume of radioactive waste compared to volumes arising from other decommissioning activities.

1.0 INTRODUCTION

Since the initiation of the Manhattan Project in the early 1940's, several thousand sites throughout the United States have conducted activities using naturally radioactive materials, man-made radioactive materials, and/or radiation producing devices. Several hundred of these sites, and individual facilities at some of the sites, are no longer used and have been shut down. Some have been decontaminated and decommissioned, while others are awaiting decommissioning. Eventually, all such sites or facilities will need to be decommissioned. Although there are no federal regulations that stipulate the actions to be taken to terminate a license for these sites and facilities, guidelines for decontamination have been provided by the NRC licensing staff since the early 1960's. (USNRC78) However, guidelines are needed to establish procedures for the decontamination and decommissioning of all nuclear facilities, including radioisotope and radiopharmaceutical manufacturers and suppliers.

1.1 EPA Program and Objectives

The Nuclear Regulatory Commission (NRC), Department of Energy (DOE), and Environmental Protection Agency (EPA) are collectively involved in the preparation of procedures and guidelines for decontamination and decommissioning which will assure that nuclear facilities are retired in a manner acceptable to the various regulatory agencies and the general public, and which can be achieved by the nuclear industry. Technical assessments must be made to establish procedures for the decontamination and decommissioning of all nuclear facilities, including those facilities which manufacture or supply radioisotopes and/or radiopharmaceuticals. The NRC and agreement states are responsible for licensing this type facility. Currently, plans for decontamination and decommissioning must be developed which are determined to be adequate by the licensing authority before a license is granted. The EPA assumes responsibility for ensuring public health, following decontamination and decommissioning.

The EPA is currently developing a series of environmental protection standards for the disposal of radioactive waste. To assist in this process, there is need for federal radiation protection guidance on

residual radioactivity for use in planning and implementing decontamination and decommissioning of nuclear facilities and materials. In support of the development of such guidance, which is to be proposed in 1982 and finalized in 1983, technical assessments are required to characterize problem areas, evaluate the risks, examine the available methods of decontamination and decommissioning, and evaluate any occupational risks associated with these methods. An analysis of techniques for demonstrating compliance, a review of existing standards and regulations related to decontamination and decommissioning are also necessary. In order to provide information for the EPA to use in their eventual plans to develop standards, ERC has estimated waste volumes which may result from decontamination and decommissioning of facilities involved with the manufacture and supply of radioisotopes and radiopharmaceuticals.

1.2 Scope of the Present Project

There are thousands of non-fuel-cycle facilities in the United States where radioactive material is used for medical purposes under specific licenses of the NRC or the agreement states. Operations involved in these facilities vary from the use of short-lived radioisotopes by a physician to large-scale production of radioisotopes or radiopharmaceuticals in nuclear reactor and accelerator facilities. (An66, Mu81)

The first artificially produced radioisotopes became available during the period 1929 to 1935 when cyclotrons were first developed. These isotopes were almost immediately used in medical research throughout the United States as well as in many other countries. After 1945, larger quantities and varieties of radioisotopes were produced due to the development of nuclear reactors. Shortly following this period of rapid growth of radioisotope production and availability, many pharmaceutical and other companies in the United States and abroad have prepared radioactively-labeled compounds. Today, radioisotopes produced in reactors and cyclotrons are widely used for medical research, diagnostic, and therapeutic purposes. Facilities involved in the manufacture and supply of radioisotopes and radiopharmaceuticals will require periodic decontamination and eventual decommissioning, and radioactive wastes will arise from these operations.

The purpose of this work effort was to assist EPA by compiling information on the location and types of radioisotope and radiopharmaceutical manufacturers and suppliers in the U.S. and estimating waste volumes resulting from the decommissioning of these facilities. A list has been compiled of radioisotope and/or radiopharmaceutical manufacturers currently operating and those which have had their licenses retired or transferred. In addition, the nature and volumes of wastes resulting from decontamination and decommissioning at representative facilities and problems likely to be encountered in these operations were identified.

2.0 METHODOLOGY

2.1 Approach

There are many facilities which manufacture and/or supply radioisotopes and radiopharmaceuticals in the United States. Their operations vary in terms of production volumes, the types of radioisotopes produced, and the chemical form in which the radioisotopes are supplied. There are as many production volumes as there are manufacturers and the variety of products make it necessary to consider some operations together. Although some radioisotope manufacturers are not necessarily involved with the production of radiopharmaceuticals, these operations have been grouped together since considerations during decommissioning will not be significantly different. Nuclear pharmacies were also identified in this study since their numbers are increasing rapidly and they serve as middlemen between manufacturers (who are also distributors) and users of radiopharmaceuticals. Their activities range from measuring doses of radioactive drugs that have been manufactured elsewhere to performing complex chemical procedures and preparing radioactive drugs from raw materials. (Te79) The operations of these facilities will be discussed in more detail in section 2.5.

Not all radioisotope and radiopharmaceutical manufacturers and suppliers are regulated by the same authorities. The facilities located in non-agreement states are licensed by the NRC in their respective regions. Those in agreement states are controlled by the individual states, and

thus, were more difficult to compile. Nuclear pharmacies are regulated by both states and the NRC in agreement states because of reactor produced isotopes, and by the NRC in non-agreement states.

There was no single reference available containing a complete list of these facilities. The number of manufacturers, production of radioisotopes, and functions within the facilities change with the market and thus complicate the categorization and estimation of radiological concerns. Several different approaches were used to compile a list of sites producing and/or supplying radioisotopes and radiopharmaceuticals. Initially, radiological control offices of each of the 50 states, Puerto Rico, and the District of Columbia were contacted and a literature review was made. Numerous contacts were made later with people in government, industry, and academia to acquire information as to the general concerns during operations and decontamination and decommissioning at these facilities. These approaches are described in detail in the following sections.

2.2 Literature Review

In a previous research effort, ORNL subcontracted with ERC to review and evaluate terminated byproduct material licenses (10 CFR Part 30) from docket files supplied by the NRC. Over 10,000 of these licenses and general files were evaluated for potential radiological concern associated with residual levels of radioactivity. In addition, the specific types of operations conducted at these licensed facilities were listed (e.g., "Manufacturing" and "Distribution") during the review of the docket files. This enabled ERC to search the computer files and identify facilities with operations of interest. An NRC nuclear byproduct list, current to 1979, contained facilities with the operational heading of "Manufacturing, Services, and Distribution Licenses." Many of these facilities overlapped with the facilities listed in the docket file review performed by ERC, but some were used to supplement the overall list. Partial lists of radioisotope and radiopharmaceutical manufacturers and suppliers were found in a few literature references, but the primary purpose of these publications was not the compilation of complete listings of the facilities. Due to a rapidly expanding and mobile nuclear pharmacy

industry, a complete listing of these facilities in the literature was unavailable.

A number of useful textbooks containing subject matter in nuclear medicine and radioisotope production were used to compile technical information on specific techniques and handling considerations used in the production of radioisotopes and the modification of these into radiopharmaceuticals with unique biological and radiological functions. References were obtained from the Central Research Library at the Oak Ridge National Laboratory, the Medical Library of Oak Ridge Associated Universities, and the Physicians' Library at the Veteran's Administration Hospital in St. Louis, Missouri.

Pertinent documents prepared by the EPA, NRC and DOE were used to compile technical and regulatory information. The documents "Industrial Research Laboratories of the United States, 16th Edition, 1979," (Ca79) and "Nuclear Research Index," (Pe76) were reviewed to supplement the docket list of radioisotope and radiopharmaceutical manufacturers.

In addition, a literature search was conducted for information specifically related to the decontamination and decommissioning of nuclear facilities. Data base searches at the Information Center Complex (ICC) of the Oak Ridge National Laboratory (ORNL) and the DOE Technical Information Center (TIC) in Oak Ridge were used in an attempt to locate pertinent documents. Personal contacts with personnel involved in isotope production and sales at ORNL and New England Nuclear Corporation were useful in locating additional information sources.

The DOE Technical Information Center (TIC) accessed the Energy Data Base and Nuclear Science Abstracts Data Base using the keywords "Decontamination and Decommissioning." In addition, the TIC Research in Progress Data Base was searched using the keywords "Radiopharmaceuticals and Radioactive Wastes." These data base searches did not provide documentation specific to the decontamination and decommissioning of radioisotope and radiopharmaceutical manufacturers and suppliers. However, they did indicate five references which were related to this particular

study. Documents which were not referenced in this study but contain related and potentially useful information are listed in Appendix C.

The ICC at ORNL has access to energy and nuclear related information data bases. A search of the Integrated Waste Data Base for the keyword, Remedial Action, proved to be the most useful literature search in this study. In this search, a document prepared by E.S. Murphy of Pacific Northwest Laboratory was found to contain extremely valuable information concerning the decontamination and decommissioning of a reference radioisotope and radiopharmaceutical manufacturer and supplier. This document entitled "Technology, Safety and Costs of Decommissioning Reference Non-Fuel-Cycle Nuclear Facilities," (Mu81) proved to be the most useful compilation of technical information pertinent to this study. This document was used extensively in the description of specific labeling laboratories and associated equipment.

2.3 Other Sources of Information

2.3.1 Contacts with State and Territorial Governments

A staff member of the NRC (Region III) provided a list of manufacturers in the non-agreement states, but could not supply a comparable list for agreement states. (Ad81) In order to compile a comprehensive list for both agreement and non-agreement states, letters were sent to the radiological control offices of the 50 states, the District of Columbia and Puerto Rico. Figure 2.1 is a sample of the form letter sent to various states. ERC requested reference material or sources of information from each state or territory pertaining to the items listed below:

- o Radiopharmaceutical manufacturers and suppliers
- o Radioisotope manufacturers and suppliers
- o Accelerator facilities
- o Independent research and development institutions

Forty-five states, Puerto Rico, and the District of Columbia, responded to our request for information. Five states (Alabama, Colorado, Maryland, Massachusettes, and North Carolina) were unable to supply the requested information due to legislative constraints or manpower limitations.

August 18, 1981

<gender> <first> <last>
<where>

Dear <gender> <last>:

Evaluation Research Corporation has a contract with the Environmental Protection Agency to characterize problems that may be encountered in the decontamination and decommissioning of facilities which are or were formerly licensed by the U.S. Nuclear Regulatory Commission or Agreement States, and with registered accelerator facilities. Our interests are restricted to those used to manufacture radiopharmaceuticals and radioisotopes and independent research and development institutions.

If you have a listing of facilities used for the manufacture of radiopharmaceuticals and radioisotopes and of independent research institutions in your State we would appreciate receiving a copy of the list. We are also compiling information on the likely radiological conditions of the sites and facilities. Any sources of information you have or are aware of concerning the types of operations and/or types and quantities of radionuclides authorized for possession, would be very helpful.

The U.S. Bureau of Radiological Health, "Report of State and Local Radiological Health Programs" Fiscal Year 1977, (HEW Pub. No. 78-8034) lists the number of accelerators registered by your state but no information is given as to type or location. Our data base and library searches have provided specific identification for relatively few of the accelerators listed for your State. Again, if information or references are available we would like to receive a copy of the publication or the publication name and number.

If you have any questions with respect to this enquiry please contact me or Ms. Joann Epler (Ph. 615-482-7973). Thank you for your consideration.

Sincerely,

Donald Jacobs
Manager, Oak Ridge Operations

DGJ:mgr

Figure 2.1 Sample Form Letter Sent to States

Several contacts in government and industry were helpful in the compilation of a list of nuclear pharmacies in the United States. Don Hamilton, the Assistant Chief of the Nuclear Medicine Branch of the Food and Drug Administration (FDA), supplied a list of commercial nuclear pharmacies. He noted that many nuclear pharmacy operations are contained within large medical centers and would not require state licensing, as they function solely for the hospital. To supplement this FDA list, numerous other contacts were made with industry and state pharmacy boards. The headquarters for the two largest companies in the nuclear pharmacy industry, Nuclear Pharmacy, Inc. (Albuquerque, NM) and Pharmatopes (Toledo, OH) were contacted to determine the locations of their nuclear pharmacies throughout the United States. The branch locations of these two companies account for 57% of the operating nuclear pharmacies. (Sh81) In addition, numerous Secretaries of the State Boards of Pharmacy were contacted to supplement the list. Finally, selected nuclear pharmacies were contacted and asked to supply competitors in their areas so that smaller companies could be identified.

2.3.2 Other Contacts

A variety of contacts were also made with staff members in the nuclear pharmacy industry, at DOE facilities, private industry, and academia. Staff members from the following organizations were contacted:

1) Nuclear Pharmacies (See Appendix B),
2) Food and Drug Administration
3) State Secretaries NABP
4) Nuclear Regulatory Commission
5) Environmental Protection Agency
6) Oak Ridge National Laboratory
7) Mound Laboratory
8) Purdue University
9) Oak Ridge Associated Universities
10) New England Nuclear Corporation, and
11) Mallinckrodt Diagnostics.

Although these contacts were extremely helpful in the final compilation of the lists of manufacturers and suppliers, very few were able to provide information on specific waste volumes generated from private manufacturers and suppliers during decontamination and decommissioning since this information is proprietary in nature.

2.4 Assumptions for Decontamination and Decommissioning

2.4.1 Regulatory Considerations for Decontamination and Decommissioning

Licenses for non-fuel cycle nuclear facilities in non-aggrement states are issued by the NRC under 10 CFR Part 30, "Rules of General Applicability to Domestic Licensing of Byproduct Material," 10 CFR Part 40, "Domestic Licensing of Source Material," and 10 CFR Part 70, "Domestic Licensing of Special Nuclear Material. Licenses are issued by NRC agreement states under the terms of 10 CFR Part 150, "Exemptions and Continued Regulatory Authority in Agreement States Under Section 274." Neither 10 CFR Part 30, 40 nor 70 stipulates specific decommissioning actions that must be taken prior to termination of a facility license. However, some NRC guidance does exist that defines residual contamination levels for facilities and components prior to release for unrestricted use. (Mu81)

Guidelines for decontamination have been provided by the NRC licensing staff since the early 1960's. The values for acceptable radioactive surface contamination given in the June, 1980 "Guidelines" (Nu80) are currently used as the standard for license termination and facility release, and are so recognized in the recently proposed American National Standards Institute Standard (ANSI N13.12) on "Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be released for Uncontrolled Use." The draft ANSI standard is intended to provide guidance on acceptable limits for the release of radioactive surface contaminated materials and equipment for unrestricted use. These limits are generally the same as those used in the 1980 NRC guidelines. (Mu81) Table 2.1 shows the published and calculated guidelines of acceptable residual surface contamination (NRC guidelines and draft ANSI Standards). (ANSI78, Nu80)

2.4.2 Assumptions for Representative Laboratories and Associated Equipment Requiring Decontamination and Decommissioning

The laboratories referred to in this study are generic in nature and are believed to be representative of real facilities and associated components. Processors of radioactive materials incude those companies

Table 2.1 Comparison of Calculated and Published Guidelines for Acceptable Residual Surface Contamination

Isotope	Residual Surface Contamination that Results in 5 mrem/year to Exposed Individual[a]		NRC Guidelines[b] on Total Residual Surface Contamination	Draft ANSI Standard[c] on Total Residual Surface Contamination
	uCi/m^2	$d/m/100\ cm^2$	$(d/m/100\ cm^2)$	$(d/m/100\ cm^2)$
^{3}H	950	21,000,000	5,000 (0.2 mrad/hr)[d]	5,000
^{14}C	80	1,800,000	5,000 (0.2 mrad/hr)[d]	5,000
^{125}I	0.25	5,500	100	Nondetectable[e]
^{137}Cs	0.28	6,200	5,000 (0.2 mrad/hr)[d]	5,000
^{241}Am	0.00038	8.4	100	Nondetectable[e]

[a]The estimated residual radioactive contamination that will result in a maximum annual dose of 5 mrem to a critical organ. The scenario for exposure involves an individual working for 40 hr/wek, 50 wk/yr in a large room cntaminated with individual isotopes. A resuspension factor of 5×10^{-6} m^{-1} and a breathing rate of 230 cm^3/sec are assumed. (A resuspension factor of 5×10^{-5} m^{-1} is assumed for iodine.)

[b]Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material, U.S. Nuclear Regulatory commission, Washington, D.C., November 1976.

[c]Draft American National Standard, Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use, ANSI N13.12 (Draft), American national Standards Institute, New York, NY, August 1978.

[d]Average radiation limits associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/hr at 10 cm, measured through not more than 7 milligrams/cm^2 of total absorber.

[e]The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of contamination spread over 100 cm^2 (i.e., 220 $d/m/100\ cm^2$).

which manufacture and distribute radiopharmaceutical, radiochemical, and sealed radioactive sources used by medical, academic and industrial licensees. It is assumed that the preparation of labeled compounds or radioactive sources is performed in separate rooms or separate work places in ventilated enclosures such as hoods, glove boxes, and hot cells.

Several different production laboratories have been studied and characterized for this report. The radioactive labeling of organic chemicals is common in research. The most common labeling agents for hydrocarbons and other chemicals are ^{3}H and ^{14}C; therefore, laboratories which produce these nuclides have been included in our discussion. In addition, radioiodine (^{125}I, ^{131}I) is used as a labeling agent. The laboratory for the production of this nuclide has been included because radioisotopes of iodine are radiotoxic and highly volatile. Their use and production requires special equipment and procedures to ensure proper containment and adequate filtration of the exhaust from fume hoods and hot cells.

Sealed sources are widely used for many purposes and contain various quantities of radioactivity. Most of the encapsulated radionuclides are byproduct materials and are produced in cyclotrons or reactors. A generic laboratory used to manufacture ^{137}Cs sealed sources has been considered here also. The main concern at one of these labortories would be penetrating gamma radiation.

One additional laboratory has been included in our study, a laboratory used to process ^{241}Am for use in sealed sources. As an alpha-emitter, ^{241}Am can be very hazardous if inhaled or ingested.

To summarize, separate laboratories used to process the following radioisotopes have been selected for discussion:

- o ^{3}H-labeled compounds,
- o ^{14}C-labeled compounds,
- o ^{125}I-labeled compounds,

- o ^{137}Cs-sealed sources, and
- o ^{241}Am-sealed sources.

It is also assumed that the facilities used for the manufacture of radiochemicals are similar to those used for radiopharmaceuticals. However, it is recognized that short-lived radioisotopes will be the major consideration of radiopharmaceutical manufacturers. Radioisotope manufacturers may be involved with both short and long-lived radioisotopes. It is assumed that the use of sealed sources generally requires the radioisotope to be relatively long-lived (e.g., several years).

The descriptions of the various laboratories includes estimates of residual contamination levels on building surfaces and laboratory components at the time of decommissioning. These levels were based on experience at a large, commercial manufacturer of radioisotopes and radiopharmaceuticals (New England Nuclear Corporation). The specific dimensions and quantities assumed for laboratory equipment are described in section 3.2.

Several addditional assumptions were required concerning the methods of decommissioning. It was assumed that these facilities are located in an urban or suburban setting. These radioisotope laboratories are generally part of a larger, multipurpose operation that continues to operate after the facilities of interest are decommissioned; therefore, there is an incentive to prepare these facilities for unrestricted use in a fairly short period of time following the termination of operations. Also, in almost all cases, entire facilities will not be decommissioned but specific laboratories, such as those described in this study, are periodically surveyed for the presence of contamination.

Assumptions which are more specific to the laboratory being described (e.g., quantity of equipment) are addressed in Section 4.2.

2.5 Categorization of Facilities

The use of radioactive materials in the medical and industrial sectors has grown enormously during the past decade due to the increased production and availability of these materials. Their application encompasses many areas ranging from radioactive tracers in medicine to large-scale food irradiation and power supplies in space exploration. (Ei72)

There are many facilities which manufacture and/or supply radioisotopes and radiopharmaceuticals in the United States. The operations in these facilities vary in terms of production volumes, the types of radioisotopes manufactured, and the chemical forms in which these products are ultimately supplied. Production volumes vary among manufacturers, and the variety of the end products make it necessary to consider the decontamination and decommissioning concerns and methods together.

Individual clinicians converted radioisotopes into radiopharmaceuticals when the production of isotopes began. As the demand for these medical products increased, pharmaceutical and other companies undertook the commercial preparation of radiopharmaceuticals. The number of facilities manufacturing radiopharmaceuticals has grown rapidly and has provided for the emergence of a new industry: the nuclear pharmacy.

Nuclear pharmacies are beginning to emerge as middlemen between manufacturers (or distributors) and users of radiopharmaceuticals. These pharmacies buy bulk isotopes from the manufacturers, synthesize the radiopharmaceutical with reagent kits, and distribute them to users such as hospitals, physicians, universities, and medical and research laboratories. These radiopharmaceutical users are not addressed in this study. In 1977, it was estimated that about 21 nuclear pharmacies were licensed to operate in 14 states. (Te79) Today, our figures indicate that this number has increased to approximately 100 nuclear pharmacies in 37 states and the District of Columbia.

3.0 DESCRIPTION OF FACILITIES

3.1 Facility Characterization

3.1.1 Location of Radioisotope and Radiopharmaceutical Manufacturers and Suppliers

Partial lists of radioisotope and radiopharmaceutical manufacturers and suppliers have been presented in recent studies. (Te79, Tu76) However, these included major manufacturers and did not list some of the smaller companies, which in fact are much more numerous. In order to compile a more complete list of manufacturers and suppliers a variety of methods and sources were used, as described in Section 2.0. In addition, nuclear pharmacies were singled out as a new industry involved in the supply of radiopharmaceuticals. These manufacturers and nuclear pharmacies identified in this study are listed by state in Appendices A and B, respectively.

Tables 3.1 and 3.2 show the number of manufacturers and suppliers by state and by NRC region, respectively. About 45% of the manufacturers were located in NRC region 1. The states having the most manufacturing and supply facilities (determined by number of licenses) were Illinois (52), New Jersey (51), Massachusetts (47), Pennsylvania (41), California (39), Ohio (35), Connecticut (23), New York (21), and Michigan (16). Together, these represent over 65% of the total 458 manufacturers in the U.S. Only a few percent of the manufacturers listed are involved with the large-scale production of radioisotopes as raw material. Many of the companies listed in Appendix A may receive radioisotopes in various forms from outside industries and may actually be involved in the manufacture of devices that house these radioisotopes.

Nuclear pharmacies identified in each state are tabulated in Appendix B. Tables 3.3 and 3.4 show the number of nuclear pharmacies by state and by NRC region, respectively. It should be noted that nuclear pharmacies are very mobile and that their locations will change more frequently than manufacturing facilities.

Table 3.1
Number of Radioisotope and Radiopharmaceutical
Manufacturers and Suppliers by States or Territory

State	Number of Facilities	State	Number of Facilities
Alabama	0	Nebraska	0
Alaska	0	Nevada	0
Arizona	2	New Hampshire	1
Arkansas	0	New Jersey	51
California	39	New Mexico	2
Colorado	2	New York	21
Connecticut	23	North Carolina	0
Delaware	2	North Dakota	0
Washington DC	3	Ohio	35
Florida	3	Oklahoma	7
Georgia	3	Oregon	2
Hawaii	1	Pennsylvania	41
Idaho	0	Puerto Rico	5
Illinois	52	Rhode Island	2
Indiana	10	South Carolina	0
Iowa	2	South Dakota	2
Kansas	1	Tennessee	3
Kentucky	1	Texas	11
Louisiana	2	Utah	2
Maine	4	Vermont	3
Maryland	7	Virginia	11
Massachusetts	47	Virgin Islands	1
Michigan	16	Washington	1
Minnesota	11	West Virginia	2
Mississippi	0	Wisconsin	10
Missouri	13	Wyoming	0
Montana	1		
		Total	458

Table 3.2
Number of Radioisotope and Radiopharmaceutical Manufacturers and Suppliers by NRC Region

NRC Region	Number of Facilities	%
I (ME, VT, NH, MA, CT, RI, NY, PA, NJ, DE, MD, DC)	205	45
II (VA, WV, KY, NC, TN, SC, GA, FL, AL, MS, PR, VI)	29	6
III (OH, IN, MI, WI, MN, IL, MO, IA)	149	33
IV (AR, LA, TX, OK, KS, NE, SD, ND, MT, WY, UT, NM, CO, ID)	30	6
V (WA, OR, CA, NV, AZ, AK, HI)	45	10
TOTAL	458	

Table 3.3

Number of Nuclear Pharmacies by State or Territory

State	Number	State	Number
Alabama	1	Montana	0
Alaska	0	Nebraska	0
Arizona	2	Nevada	1
Arkansas	0	New Hampshire	0
California	11	New Jersey	1
Colorado	4	New Mexico	2
Connecticut	2	New York	2
Delaware	0	North Carolina	3
Washington, D.C.	2	North Dakota	1
Florida	10	Ohio	7
Georgia	3	Oklahoma	2
Hawaii	1	Oregon	1
Idaho	0	Pennsylvania	4
Illinois	2	Puerto Rico	0
Indiana	2	Rhode Island	0
Iowa	1	South Carolina	1
Kansas	1	South Dakota	0
Kentucky	3	Tennessee	3
Louisiana	2	Texas	7
Maine	0	Utah	1
Maryland	1	Vermont	0
Massachusetts	0	Virginia	2
Michigan	3	Washington	1
Minnesota	2	West Virginia	1
Mississippi	1	Wisconsin	1
Missouri	2	Wyoming	0
		Total	97

Table 3.4

Number of Nuclear Pharmacies Identified by NRC Region

NRC Region	Number of Facilities	%
I (ME, VT, NJ, MA, CT, RI, NY, PA, NJ, DE, MD, DC)	12	12
II (VA, WV, KY, NC, TN, SC, GA, FL, AL, MS, PR, VI)	28	29
III (OH, IN, MI, MN, WI, IL, MO, IA)	20	21
IV (AR, CA, TX, OK, KS, NE, SD, ND, MT, WY, UT, NM, CO, ID)	20	21
V (WA, OR, CA, NV, AZ, AK, HI)	17	18
TOTAL	97	

3.1.2 Use of Radioisotope and Radiopharmaceutical Manufacturers and Suppliers

Since the beginning of the nuclear age in the early 1940's, the production of radioisotopes has evolved from small scale laboratory operations, using charged-particle accelerators or natural Ra-Be neutron sources, to large-scale operations involving nuclear reactors, accelerators, and isotope generators. The use of radioisotopes has grown from the initial experimental use and the use of ^{239}Pu for nuclear weapons to many scientific areas ranging from use in medical tracer studies to large-scale food irradiation and power supplies in space exploration. (Ei72) Sealed sources are manufactured to be used as items such as reference standards, moisture probes, quality control instruments, therapy units and smoke detectors. (Nu81)

3.1.3 Operating Lifetime

It is very difficult to estimate the operating lifetime of facilities involved in the manufacture and supply of radioisotopes and radiopharmaceuticals for the following reasons:

1) It is unlikely that an entire facility will be decontaminated and decommissioned. Decontamination and decommissioning, in most cases, is limited to a specific laboratory and associated equipment used in the manufacturing or research process. Therefore, it is more realistic to determine operating lifetime for the equipment and structural components in the laboratory.

2) The production volumes, types of radioisotopes manufactured, and the chemical forms in which the radioisotopes are supplied vary greatly between manufacturers. To relate an operating lifetime with these parameters is unrealistic.

3) Manufacturers have different housecleaning procedures and vary in their frequency of cleanup procedures.

It is assumed that the components of all listed facilities will require decontamination by the year 2000 even if the entire facility is not decommissioned.

3.2 Waste Characterization

Much of the technical information used in the following sections concerning waste forms, laboratory equipment, and radioisotope inventories was taken from a study sponsored by the Nuclear Regulatory Commission (NRC) which considered the hypothetical decommissioning of non-fuel cycle nuclear facilities. This study included safety considerations and the probable costs of decommissioning these facilities. (Mu81) This document provided valuable input to the characterization of the problems associated with the decontamination and decommissioning of radioisotope and radiopharmaceutical manufacturers and suppliers licensed by the NRC or the States.

It was not pertinent to the present study to include examples of the decommissioning of all the categories of non-fuel cycle facilities described in the NRC study. However, much of the information concerning generic facilities and accompanying equipment could be compared to specific facilities in this study concerning radioisotopes and radiopharmaceutical manufacturers. Much of the information sought in the present study was proprietary in nature, but by examining selected facilities and some components and operations that are common to many facilities, a reasonable estimate of volumes of contaminated materials and decommissioning needs in typical facilities was possible.

3.2.1 Radiological Characteristics

The majority of radiological waste generated from radioisotope and radiopharmaceutical manufacturers and suppliers will consist of surfaces and equipment contaminated with tritium and nuclear byproducts (atomic numbers 3-83). Table 3.5 lists some commonly produced and distributed radioisotopes and the half-life of each.

Facilities involved in the processing and packaging of radiochemicals are similar to those used for radiopharmaceuticals. Both short-lived nuclides (such as ^{24}Na, ^{64}Cu, ^{82}Br, and ^{131}I) and long-lived nuclides (such as ^{14}C, ^{3}H, ^{60}Co, ^{90}Sr, ^{137}Cs, and ^{241}Am) are processed. The radiochemicals are most often prepared as radioactive salts in HCl,

Table 3.5

Radionuclides Commonly Produced by Radioisotope Manufacturers

Nuclide	Half-Life	
^{3}H*	12.28	yr
^{14}C*	5730	yr
^{32}P	14.3	days
^{35}S	88	days
^{55}Fe	2.7	yr
^{60}Co	5.27	yr
^{85}Kr	10.72	yr
^{90}Sr	28.6	yr
^{125}I*	60	days
^{131}I	8.05	days
^{137}Cs*	30.17	yr
^{241}Am*	432.0	yr

*Generic laboratories used for the production of these radioisotopes are addressed in Section 4.

HNO_3, or normal saline solutions. Iodine-125 and ^{131}I are prepared in solutions of NaOH. Radiochemicals are packaged in glass or plastic bottles, and if necessary, are shipped in shielded containers. Quantities per package range from a few microcurues to tens or hundreds of millicuries. (Mu81)

Sealed sources are manufactured for use as reference standards, radiotherapy units, gamma irradiation sources, and for incorporation in instruments such as moisture probes, quality control devices, and smoke detectors. In general, these uses require long-lived isotopes. Reference sealed sources usually are small sources that range in activity from a fraction of a microcurie up to a few millicuries. Sources for industrial uses (such as industrial gauging, oil well logging, etc.) range in activity from a few millicuries up to tens of curies. Gamma irradiator sources using ^{60}Co or ^{137}Cs are high-activity sources with strengths in the kilocurie range. (Nu81)

3.2.2 Physical Characteristics

Fume hoods, glove boxes, hot cells, laboratory work benches, ductwork, and drains are common components used in operations involving the manufacture and supply of radioisotopes and radiopharmaceuticals, and will eventually need to be decontaminated and decommissioned. In addition, walls, floors, and storage areas should also be surveyed and decontaminated, if necessary.

The waste forms contained in a fume hood will depend upon the particular radioisotopes processed in the hood. As mentioned earlier, it is assumed that facility equipment is used in processing only a particular radioisotope. Fume hoods are commonly used to work with a variety of radioisotopes and radiopharmaceuticals. Hoods may be constructed of wood or steel and may have interiors constructed with masonite or asbestos board floors and walls. These floor and wall surfaces are usually painted with a chemically resistant plastic-base paint. Newer fume hoods are typically of steel construction with interior surfaces of stainless steel, aluminum, or masonite. (Mu81, Sa79, Tu76)

Exhaust ductwork may be constructed of stainless steel, glass fiber, asbestos pipe, iron, aluminum, or sheet metal. Several coats of corrosion-resistant plastic-base paint may be applied to surfaces made of iron or aluminum. Fume hoods used in radiological work usually exhaust through a high-efficiency particulate air (HEPA) filter located in the exhaust duct immediately above the hood; charcoal filters may also be present when ^{131}I is being used or processed. (Mu81, Sa79, Tu76) All of the facilities in this report use some form of fume hood.

A glove box is used for operations where there is a high potential for contamination from radioactive or toxic dust or vapor. It is an enclosure permitting safe manual operations with radioactive or toxic material through positive confinement of the material. The glove boxes are designed for bench-top use in common laboratory operations such as stirring, pipetting, centrifuging, drying, weighing, etc. Unshielded glove boxes may be used when working with low-energy radioisotopes, while it may be necessary to add shielding or to use high density gloves when working with high energy gamma, X-ray, and beta emitters. The use of remote manipulators and hot cells may be necessary for use with large quantities of high energy gamma emitters, such as curie quantities of ^{60}Co or ^{137}Cs. (Mu81)

Hot cells and manipulators are also components which may need to be decontaminated and decommissioned. Hot cells are used when working with high levels of beta- and gamma-emitters to assure protection from penetrating radiation. The walls of hot cells are generally made of lead bricks or high-density concrete. The cell walls are lined with strippable paper or other smooth materials to facilitate decontamination as this prevents the accumulation of radioactive materials in cracks between lead bricks. Master-slave manipulators are used in conjunction with the hot cells so that processing operations are isolated. (Mu81, Tu76)

Considerations and methods for the decontamination and decommissioning of these and other common components in specific isotope laboratories are described in detail in Section 4.0.

3.2.3 Chemical Characteristics

Although this study is concerned with the decontamination and decommissioning of radioactively contaminated components, there is also concern about the chemical agents which are used in the actual labeling process or in the processing and separation stages of radioisotope production. The chemical form of the waste may be an important factor affecting the transport of radioactive materials in the environment following disposal. Solutions used to remove surface contamination generally consist of acids (e.g. HCl) or complexing agents (e.g. EDTA). A typical manufacturing company or supplier may be involved with the production of labeled organic compounds, a variety of inorganic radiochemicals, and radiopharmaceuticals specifically used for diagnostic and therapeutic purposes; each of these compounds may differ in its mobility and behavior in the disposal environment.

In some cases it may be desirable to neutralize acids prior to disposal. It may be necessary to consider the chemical toxicities of a variety of organic compounds (including possible carcinogens), acids, hydroxides, and other compounds used in the manufacturing and supply industry.

3.2.4 Handling Considerations

The inventories of radioactive materials in typical non-fuel cycle facilities such as radioisotope manufacturers and suppliers, are usually several orders of magnitude smaller than those associated with typical fuel cycle facilities. Workers involved in the decommissioning of these facilities generally experience the same levels of exposure as workers engaged in normal facility operation. An exception may be for facilities engaged in the manufacture of ^{241}Am sealed sources. As an alpha-emitter, ^{241}Am presents a significant hazard only from internal exposure (i.e., inhalation or ingestion). Significant quantities of airborne radioactivity may be generated during the decommissioning of the reference ^{241}Am laboratory, and during decommissioning, workers may be required to wear protective respiratory equipment. Precautions must also

be taken when decommissioning components contaminated with ^{137}Cs since there is a potential for direct external exposure.

4.0 GENERIC FACILITY DESCRIPTION

Radioisotopes are used in a variety of operations that range from the occasional use of short-lived isotopes by a physician to the large-scale production of radioactive materials. The reference laboratories described in this study include individual laboratories that are representative of facilities for the production of radioisotopes, derived radiochemicals and radiopharmaceuticals, and the rapidly growing nuclear pharmacies. Actions required for decommissioning these facilities can vary from simple, relatively inexpensive administrative procedures to extensive decontamination and disposal representing much larger expenditures. Information on experience with the D&D of such a facility is available from the New England Nuclear Corporation (NEN). (Mu81)

This facility is representative of the facilities categorized in this study and manufactures and supplies short- and long-lived radioisotopes and radiopharmaceuticals. NEN periodically decontaminates and renovates individual laboratory facilities to meet the changing requirements of their manufacturing operations. They have also decommissioned entire buildings that have been used for the manufacture of labeled chemical compounds (radiochemicals and radiopharmaceuticals) and radioactive sources.

The specific NEN facility was located at 615 Albany Street, Boston, Massachusetts. After decommissioning, the facility was released for unrestricted use in 1976. (Mu81) The building was an old, loft-type building with brick exterior and wood interior, containing five floors and a basement, with each floor having an area of about 3200 sq. ft. The upper four floors had been used as biochemical and organic chemical laboratories in the manufacture of compounds labeled with ^{3}H, ^{14}C, and ^{32}P. An area on the first floor was used as an assay laboratory and later as a health physics laboratory. Part of the basement was used for storage of sealed radioactive waste awaiting disposal.

A set of floor plans was prepared, a systematic procedure of radiation surveys was developed, and manual and mechanical cleaning was begun. Manual cleaning was done with scrub brushes, scrapers, sponges, and steel wool; mechanical cleaning equipment included power scrubbers, steam generator, wet vacuum cleaner, and jack hammers. The entire effort was directed toward reducing residual contamination levels below those specified in NRC guidelines (Nu80) for decontamination of facilities prior to release for unrestricted use.

Laboratory furnishings (benches, hoods, tables, cabinets, etc.) that were below guideline limits or were easily decontaminated were reused or disposed of by conventional means. Furniture and equipment that could not be easily decontaminated were packaged and disposed of as radioactive waste. In practically all cases it was considered not economically feasible to decontaminate ductwork. All ductwork associated with hood exhaust systems and some air conditioning ductwork was removed and disposed of as low-level radioactive waste. Glove boxes that were not reclaimed were spray painted to fix residual contamination, loaded with contaminated equipment, filled with a quick-setting organic foam, and shipped to low-level waste burial grounds.

The walls and ceilings were steam cleaned. The floors consisted of vinyl tile laid over plywood on top of the original floor. Where contamination occurred, the floor tiles were replaced and, if necessary, sections of the plywood were cut out and replaced. Some of the areas of contamination most difficult to decontaminate (areas not accessible for routine cleaning) were the floors underneath laboratory benches and cabinets. Drains from laboratory sinks were removed and disposed of as low-level waste. Drain risers and drain vent lines were wipe tested, found to be within acceptable limits for residual contamination, and plugged by plumbers.

Approximately 25,000 wipe tests were made for removable contamination. The entire decontamination and radiation survey operation required about 6 months to complete.

Specific volumes of equipment and waste during decontamination and decommissioning were not available for this facility. However, estimated and actual waste volumes are available for laboratories that manufacture radiopharmaceuticals, radiochemicals, and sealed sources and institutional laboratories that use radioisotopes in both sealed and unsealed source form for medical research and educational purposes. (Mu81) Reference laboratories in this report will not include institutional research and development labs since these are addressed in another document. (ERC82)

The most common radioisotope used in the nuclear pharmacy industry is ^{99m}Tc, which has a half life of about 6 hours. Long-lived isotopes are used to a lesser extent, and therefore D&D considerations will not be as great for the nuclear pharmacy as for manufacturers. Generally, equipment is removed and transported when the company is transferred. Storage vaults used for waste must be decontaminated to acceptable levels. (Fl81, Wh81)

4.1 Operating Lifetime

As discussed in Section 3.1.3, the operating lifetime of facilities involved in the manufacture and supply of radioisotopes and radiopharmaceuticals is highly variable, depending on the specific radioisotopes produced or supplied, production volumes, and numerous other factors. In most cases, specific laboratories or equipment will be decommissioned rather than entire facilities.

In this study it is assumed that the components of all radioisotope manufacturers and suppliers identified will require decontamination by the year 2000, even if the entire facility is not decommissioned.

4.2 Waste Characterization

4.2.1 Generic ^{3}H laboratory

Tritium can be produced in a number of ways. It can be produced by bombardment of a deuterium target with deuterons accelerated in a cyclotron or other high energy machine. It is also produced on a large

scale in reactors where nuclides are exposed to high flux of neutrons under controlled conditions. (NCRP80)

Tritium is often used as a labeling agent in the form of tritiated water, tritium gas, or as a metal hydride. Tritium has a relatively long half-life (12.28 years) which permits its use in studies over extended time periods. However, the longer half-life should be considered in planning the decommisssioning of a facility or laboratory.

Typical equipment and work enclosures in the generic laboratory are those used to label materials with ^{3}H and to purify these compounds. There are 5 fume hoods in this laboratory, of which three are used to handle high activity batches of reagent. The exhaust air is filtered from the hoods using roughing and high-efficiency particulate air (HEPA) filters and vented through stainless steel ductwork.

There are six glove boxes in the generic laboratory for working with the ^{3}H labeled compounds. Laboratory workbenches house equipment and non-radioactive solutions used for chemical preparations. Labeled compounds and non-radioactive materials are stored in refrigerators, freezers, and storage cabinets; some of these storage facilities can be recycled.

Estimated residual surface contamination levels of these major components in the generic laboratory at the time of decommissioning are given in Table 4.1. (Mu81) Steam cleaning can be used in decontaminating the laboratory, since all the contamination in this laboratory will be from tritium.

In the ^{3}H-labeling laboratory, the following assumptions have been made: three of the five fume hoods can be decontaminated to unrestricted release levels; two are assumed to have high levels of residual contamination which cannot be easily removed. Dust and other loose materials should be removed and packaged for disposal at a shallow land burial facility. Three of the glove boxes can be decontaminated to

Table 4.1

Residual Surface Contamination Levels in Generic Laboratories (Mu81)

Laboratory Component	Generic Laboratory Residual Surface Contamination (100 dpm/cm^2)				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Walls	<1 (10-100)[a]	<1 (10)	<.1 (1)	<1 (10)	<.02
Floors	<1 (50)	<1 (50)	<.1(1)	<1 (50)	<.02 (1)
Bench Tops	<1 (50)	<1 (50)	<.1 (1)	<1 (50)	<.02 (12)
Inside Hoods	1 mCi*	<100 (1000)	<1 (10)	1-10 uCi*	1 (5)
Inside Glove Boxes	10-100 mCi*	1000	10-100 uCi*	.01-1 uCi*	.01-1 mCi*
Inside Ventilation Ductwork	50-100	<100 (1000)	.2-2	1-50	<.05 (1)
Drains	--	10-50	<.1	1 (50)	--

*Listed units replace dpm/cm^2.

[a]Parenthetical values indicate residual contamination levels of hot spots.

levels of unrestricted use but the remaining two should be packaged and disposed of at a commercial facility. Laboratory benches, walls, floors, refrigerators, storage cabinets, and the freezer can all be cleaned to levels of unrestricted use. Ventilation ductwork will be sectioned and packaged for disposal along with HEPA filters, roughing filters, and fiberboard ceiling panels.

4.2.2 Generic ^{14}C laboratory

Carbon-14 is normally produced in a nuclear reactor by the reaction $^{14}N(n,p)^{14}C$. Carbon-14 has a half-life of 5730 years and is, therefore, a radionuclide of major concern when decommissioning a facility where it has been used. Most non-volatile ^{14}C-labeled organic materials at specific radioactivities up to about 100 uCi/g can be handled by much the same techniques as those used with unlabeled chemicals. The beta radiation from ^{14}C is readily absorbed by many materials of low density, such as transparent plastics and glass. Thus, even at high levels of specific radioactivity, these compounds can be safely handled if reasonable precautions are taken.

The generic facility for the manufacture of ^{14}C-labeled compounds contains equipment similar to that at an organic chemistry laboratory (e.g., distillation equipment, etc.), in addition to fume hoods and glove boxes where operations involving ^{14}C are performed. At the generic laboratory, there are 4 fume hoods and 4 glove boxes with each being separately vented through roughing and HEPA filters. Workbenches should not be contaminated in most cases. Labeled compounds are usually stored in cabinets and refrigerators. Estimated residual surface contamination levels of these components at the time of decommissioning are listed in Table 4.1 with the contamination assumed to be entirely from ^{14}C.

In the ^{14}C labeling laboratory, the following assumptions have been made: Three of the four fume hoods can be decontaminated to levels of unrestricted use while the remaining hood should be packaged and disposed of at a shallow land burial facility. Three of the four glove boxes can be decontaminated to levels of unrestricted use, while the remaining glove box should be packaged for disposal. Laboratory benches, walls, floor,

refrigerators, storage cabinets, freezer, and the sink are all cleaned to levels for unrestricted use, but the drain line must be sectioned and handled as radioactive waste. Walls can be steam cleaned and the floor and equipment surfaces are scrubbed with a decontaminating solution. Ventilation ductwork can be sectioned and handled as radioactive waste, along with HEPA filters, roughing filters, and fiberboard ceiling panels.

4.2.3 Generic radioiodine laboratories

Two iodine isotopes, ^{125}I and ^{131}I, are used extensively in nuclear medicine for both diagnostic and therapeutic purposes. These radioisotopes differ in half-life (60 days for ^{125}I and 8 days for ^{131}I) and decay mode, but the labeling process is similar.

The labeling of a chemical compound with ^{125}I or ^{131}I is usually achieved by an exchange reaction and extraction of the labeled material. Radioiodine labeling is performed in specially constructed glove boxes located inside fume hoods due to high radiotoxicity of radioiodine.

The major facility components in the generic iodine laboratory include: four fume hoods with glove boxes located inside them and with air being vented through ductwork containing charcoal, HEPA and roughing filters. The laboratory has a stainless steel sink which drains to a tank where liquid effluent is held for radioactive decay, monitored, and diluted to acceptable release levels before discharge to the sanitary sewer. This sink is only used for personal cleanliness and washing non-radioactive glassware, not liquid waste from processing operations. Other potentially contaminated components in a radioiodine laboratory include workbenches, a refrigerator, storage cabinets, and storage shelves. Assumed residual surface contamination levels for these components are shown in Table 4.1.

In the ^{125}I labeling generic laboratory, the following assumptions have been made: All four glove boxes located inside the fume hoods will be packaged for disposal while the fume hoods can be decontaminated to levels of unrestricted use. Laboratory benches, ceilings, walls, floors, refrigerators, sinks, storage cabinets, and shelves can be decontaminated to levels of unrestricted use. The drain

line from the sink and ventilation ductwork and filters should be sectioned and packaged for disposal.

4.2.4 Generic ^{137}Cs laboratory

The radioisotope ^{137}Cs has gained much attention because it is a fission product of either uranium or plutonium fuels and it is widely distributed in the environment as a result of fallout associated with atmospheric weapons tests. In addition, ^{137}Cs has been used in industry in the form of sealed sources incorporated into thickness gauges, in oil well logging, and in medicine and research as a sealed source for therapy, and as a tracer substance. (NCRP80)

During the preparation of ^{137}Cs sealed sources, the anhydrous chloride of cesium is fused with alumina at a high temperature. Following this process, the fused material is encapsulated in stainless steel. The steps in the fabrication process are performed in small hot cells using remote handling equipment (with the exception of final encapsulation and testing of individual sealed sources) due to the high gamma-emitting energies resulting from ^{137}Cs decay and the broad range of activities (curie amounts) of ^{137}Cs processed.

The major components in the generic laboratory for the manufacture of ^{137}Cs sealed sources include two small hot cells with master-slave manipulators and roughing and HEPA filters, two fume hoods also with roughing and HEPA filters, one stainless steel sink, with drainage to a tank where liquid effluent can be monitored and diluted to acceptable release levels before discharge to the sanitary sewer. (This sink is only used for personal cleanliness.) Liquid waste generated during processing operations is packaged and shipped to a commercial shallow-land burial site for disposal.

At the generic laboratory for the manufacture of ^{137}Cs sealed sources, the following assumptions have been made. The fume hoods, laboratory benches, ceiling, walls, floor, and sink can be decontaminated to levels of unrestricted use. The drain line from the sink and ventilation ductwork and filters will be sectioned and packaged for

disposal as radioactive waste. Both hot cells will be sectioned with the lead glass windows and cell lines packaged for disposal. Lead bricks will be monitored; some will be decontaminated and sold for salvage while the others will be packaged for disposal as radioactive waste. The hold-up tank should be monitored before releasing the facility.

4.2.5 Generic ^{241}Am laboratory

Sealed sources containing ^{241}Am have been used in industry for a variety of applications, such as static eliminators, X-ray excitation sources, smoke detectors, thickness gauges, and calibration sources. In addition, ^{241}Am is used as a neutron source when combined with beryllium and as a target material for producing ^{242}Cm in accelerators.

The major components in the reference laboratory for the manufacture of ^{241}Am sources include: Two fume hoods, seven glove boxes with transfer tunnels connecting each, storage cabinets, and a laboratory workbench. The generic laboratory does not have a sink. Roughing and HEPA filters are used to filter the exhaust from the hoods and glove box system. The transfer of radioactive materials between adjacent glove boxes in the manufacturing process is made through transfer tunnels.

It is assumed that the fume hoods can be decontaminated to levels acceptable for unrestricted use while the glove boxes, transfer tunnels, ventilation ductwork and filters must all be packaged for disposal.

4.2.6 Nuclear pharmacies

Nuclear pharmacies sell radiopharmaceuticals which are produced by manufacturers, such as New England Nuclear Corporation. In addition, they produce other radioisotopes which are short-lived. The predominant isotope produced is ^{99m}Tc which has a half-life of 6 hours. Other isotopes which are common in this industry are ^{67}Ga (half-life of 78 hours) and ^{201}Tl (half-life of 74 hours). (Wh81) None of these would pose a problem during decommissioning nor would radioactive waste result from their use. In fact, the industry has a history of being very mobile. Laboratories are

set up to facilitate easy dismantling and transfer of equipment to another location.

Before its operation is approved, a nuclear pharmacy must file with the state regulatory agency a diagram of the intended facility showing the location of equipment and also must file plans for temporary waste storage. Wastes are segregated according to half-life and typically stored in concrete vaults. Low-level wastes with longer half-lives are packaged and sent to a commercial burial site for disposal. Fume hoods have removable filters and ductwork which can be disassembled and moved to a new location with the filters being discarded as low-level waste. The states further require that the facility be surveyed for radiation before it is released for unrestricted use. (Fl81)

Very little radioactive waste results from the decommissioning of nuclear pharmacies because of the mobility of operations and the short-lived materials used.

4.3 Decontamination and Decommissioning Alternatives

For these reference laboratories, the following decommissioning alternatives are available:

- Decontamination is defined as the immediate removal and disposal of all radioactivity in excess of levels which would permit release of the facility for unrestricted use. Decontamination procedures do not require that nonradioactive structures and equipment be removed. (Nu81)

- Mothballing is defined as those activities required to place and maintain radioisotope and radiopharmaceutical manufacturers and/or suppliers in such conditions that the risk to safety is within acceptable bounds. It also requires that the facility can be subsequently decontaminated to levels which permit release of the facility for unrestricted use at a later date. (Nu81)

- Entombment is defined as the encasement of a facility in concrete to protect the public from radiation exposure until its radioactivity has decayed to acceptable levels. (Nu81)

Decontamination is considered to be the most likely decommissioning alternative for these facilities since this method would result in the unrestricted release of the property soon after licensed operations cease.

Mothballing would be an acceptable decommissioning alternative for such facilities as nuclear pharmacies or manufacturers of short-lived radioisotopes, where the radioactivity would decay to acceptable levels for unrestricted release within a period of a few months to a few years. This decommissioning method could also be useful if the decay of short-lived radioisotopes is followed by decontamination processes to remove remaining long-lived radioactivity. However, there are a few disadvantages inherent with the mothballing method when considering facilities with significant long-lived contamination. First, personnel who are familiar with the facility may no longer be available to aid in delayed decontamination, and second, the removal of radioactivity from contaminated surfaces usually becomes more difficult with time. (Mu81) Since most of these facilities are located in urban or suburban locations, there is an incentive to convert these facilities to an unrestricted status in a fairly short period of time following the termination of manufacturing activities. Therefore, the entombment alternative is an unlikely decommissioning method for these facilities. (Mu81)

5.0 SITE-SPECIFIC ISSUES

Data bases containing information from NRC docket files were examined for possible site-specific problems, including on-site burial and contamination.

Most facilities identified in this report use commercial radiological waste disposal services for the disposal of their radioactive waste. However, in the 1950's and 1960's, some facilities disposed of wastes by on-site burial. On-site disposal is an important consideration when planning decommissioning. These sites should be examined on an individual basis to determine the actual types and amount of materials in the waste and the current conditions. In some cases, where immediate reuse of the facility is not desired and the existing disposal is stable, it may be advisable to leave the waste in its present site. Radioactive waste

consisting of short-lived radionuclides may require only conventional disposal.

Isotopes Specialties Co., Burbank, CA disposed of ^{3}H and other byproduct materials by on-site burial. Since tritium has a 12.3 year half-life, it could still present a potential source of exposure if containment were breached. American Cyanimid, Pearl River, New York, incinerated radioactive waste, mostly byproduct materials, and then buried the ashes. Monsanto Chemical co., located at Texas City, Texas, disposed of waste on-site in the early 1960's. Central Electronic Manufacturing Co. in Danville, NJ also used this means of disposal for small quantities of materials.

Ordinarily, on-site burial is not expected to present a major problem for the decommissioning of radioisotope manufacturing and supply facilities discussed in this study. Similarly, nuclear pharmacies tend to store waste in shielded vaults until the materials have decayed to permissible levels.

There have been many instances where laboratories have been contaminated to a small degree. Most of this contamination was readily removed. There have also been a few facilities contaminated very heavily. An examination of the NRC docket files, discussed earlier, revealed that the Budd Co. in Philadelphia had many problems of contamination and overexposure. Much of the contamination was attributed to leakage from radiography sources, including ^{90}Sr.

Martin Co. operated a ^{90}Sr processing plant in Quehanna, PA (originally operated by Pennsylvania State University) for production of ^{90}Sr sources. The facility was contaminated in the early 1960's and subsequently decontaminated. Wastes were sent to ORNL and West Valley, NY. Teledyne Isotopes now operates the facility which is used to produce devices containing sealed sources.

The American Nuclear Company, Clinton, TN, was opened in the early 1960's to manufacture radioisotopes. However, the facility was closed due to extensive contamination. The company filed for bankruptcy and the

responsibility for clean-up reverted to the State of Tennessee. The bulk of contamination consisted of ^{60}Co and ^{137}Cs in a hot cell which contained about 25000 Ci of unencapsulated ^{60}Co pellets and about 8000 Ci of encapsulated ^{137}Cs pellets. Some of the ^{137}Cs pellets had ruptured, leading to contamination. The contamination had spread over the entire facility, the adjoining landscape, and into a neighboring creek. The state decontaminated the building which is now used as an auxiliary garage by Anderson County. There is still minor contamination in the facility. Eldridge and Oakes surveyed eight different locations surrounding the site in 1977. (E178) A concentration of 515 pCi/g of ^{60}Co was found in wet sediment at the center of Braden Branch, while soil at the bank contained 75 pCi/g of ^{60}Co. Unfiltered water from the creek contained 200 pCi/g of ^{60}Co and 1000 pCi/g of ^{137}Cs. Braden Branch flows into Braden Pond which is sometimes used for swimming. Sediment from this pond contained about 60 pCi/g of ^{60}Co. Cow manure taken from an adjacent field where cattle often graze contained about 5 pCi/g of ^{60}Co. (E178)

Contamination will exist in varying degrees at other facilities. These should be examined on an individual basis, with the appropriate remedial actions applied to each. In some cases, temporary storage and stabilization of the landscape will be sufficient to reduce the levels of contamination. In others, decontamination with removal of certain components and soils will be required to reduce the contamination to levels of unrestricted use.

6.0 SUMMARY AND CONCLUSION

The greatest amount of waste will be generated during the decontamination and decommissioning of facilities or laboratories involved in the large-scale manufacture of radioisotopes and radiopharmaceuticals (with the exception of special cases of accidental contamination). In addition, there is greater likelihood that longer-lived isotopes will be produced in a large-scale operation.

The majority of facilities listed in Appendix A (Manufacture, Distribution, and Service Facilities) do not manufacture radioisotopes or radiopharmaceuticals on a large scale, but may be involved with the

production of devices into which radioisotopes are emplaced and distributed to other users. At these facilities, the wastes generated during D&D would generally be very small unless the cleanup was required due to accidental releases in the laboratory.

The predominant radioisotope present in the nuclear pharmacy industry is ^{99m}Tc. It has a short half-life (about 6 hours) and would not be a problem during decontamination and decommissioning. Other typical radioisotopes found in the nuclear pharmacy are ^{67}Ga and ^{201}Tl. (Wh81) No significant waste volumes are expected to result from decontamination and decommissioning of nuclear pharmacies. Since the industry is very mobile, laboratories are set up for easy dismantling and transfer of equipment.

Wastes awaiting burial at specified burial sites are typically stored in concrete vaults and wastes are segregated by half-life. Filters are placed in ductwork which can be easily removed and transferred to a new location. When a nuclear pharmacy closes, the state requires a radiation survey in order to release the facility for unrestricted use. (Fl81)

6.1 Estimates of Waste Volumes for Manufacturers and Suppliers

The typical manufacturer of radioisotopic materials will have more than one laboratory (i.e. ^{3}H, ^{14}C, etc.) within a facility. However, the number of laboratories and components varies significantly among facilities. For this reason the following estimates have been given in ranges. The basic assumptions given in Section 4 for components in reference laboratories along with the following additional assumptions have been used to project estimates of the volume of radioactive waste generated from D&D operations at radioisotope and radiopharmaceutical manufacturers and suppliers.

The laboratory for handling tritium has been assumed to require the dsiposal of 2 fume hoods and as many as 3 glove boxes. As a result, the estimated volume for disposal is 0 to 8 m^3 for the packaged hoods and 0 to 3 m^3 for the sectioned and packaged glove boxes. The ductwork will be packaged in volumes ranging from 3 to 5 m^3. In all likelihood, the work benches will be decontaminated to levels of unrestricted use; however, they

may have to be handled as radioactive waste if the laboratory was highly contaminated. Chemical and aqueous solutions used for cleaning, along with solidified decontaminating resins, will comprise the bulk of the waste (26 to 29 m^3). The total estimate of volume of radioactive waste for this reference laboratory is 29-61 m^3. Murphy estimated that 44 m^3 of radioactive waste would arise from the decommissioning of a similar laboratory. (Mu81)

The laboratory for handling ^{14}C has been assumed to require the disposal as radioactive waste of 1 fume hood, 1 glove box, 1 sink, and ventilation ductwork. The estimated disposal volumes for these components respectively are: 0 to 4 m^3, 0 to 1 m^3, 0 to 1 m^3, and 3 to 5 m^3. About 20 m^3 of wastes packaged in 208 liter (55 gal) drums will arise from decontamination. It has also been estimated that up to eight 208 liter drums (1.7 m^3) of low-level miscellaneous laboratory supplies and trash will have to be disposed as radioactive waste. It is estimated that 23-43 m^3 of slightly radioactive waste will arise from decommissioning a laboratory which is used for handling ^{14}C. Murphy has given a similar estimate of 34 m^3. (Mu81)

It has been assumed that the generic laboratory used to handle radioiodine will require the disposal of up to 4 glove boxes. Ductwork should also be packaged for disposal. Radioactive wastes resulting from decontamination will total 14 m^3. In all, it is estimated that 18-29 m^3 of radioactive waste will arise from decommissioning one of these facilities. Murphy has estimated the volume to be 22 m^3. (Mu81) As an alternative, this laboratory can be temporarily mothballed, allowing the activity to decay to levels of unrestricted use, essentially eliminating the need for radioactive waste disposal; this alternative is particularly attractive for the radioiodine laboratory due to the short half-lives of both ^{125}I and ^{131}I.

The generic laboratory used to handle ^{137}Cs will require sectioning and disposal of up to 2 hot cells and possibly 1 fume hood. Ventilation ductwork and 1 work bench (if badly contaminated) may also be discarded. About 12 m^3 of waste will result from the decontamination of the laboratory

surfaces and components. The total waste volume for the ^{137}Cs generic laboratory is estimated to be 16-28 m^3. Murphy has given an estimate of 20 m^3 for this type of laboratory. (Mu81)

The principal components to be disposed of in a laboratory designed for the handling of ^{241}Am will be from 3 to 7 glove boxes, tunnels which connect those glove boxes, and contaminated ductwork. Wastes arising from the decontamination of fume hoods, glove boxes, laboratory surfaces and other equipment will range from 17-22 m^3, part of which should be packaged in 113 liter drums, and overpacked by 208 liter drums. Murphy's estimated volume of waste for an ^{241}Am laboratory is 31 m^3. (Mu81)

Table 6.1 lists the five reference laboratories with estimated volumes of waste per component. The majority of the waste arises from the decontamination of the laboratories. The combined range for all five reference laboratories is approximately 110-200 m^3. For the purposes of this study, estimates of the total volume generated by all facilities in the U.S. have been made by assuming that all facilities have at least three (^3H, ^{14}C, I) of the five laboratories (representing a lower bound estimate) and that all facilities have all five laboratories (representing an upper bound). In the first case, it is assumed that the range will be 70-130 m^3 per facility which will account for any one facility. It should be noted that this range will also cover laboratories which are used to handle radionuclides and radiopharmaceuticals not directly addressed in this report. Table 6.2 lists the estimated range of waste volumes for both of these conditions per NRC region, and then gives a combined range taking the lowest and highest value for each region. Regions 1 and 3 are likely to contribute about 80% of the waste. Region 2 will generate the least (only 2000-5600 m^3). The combined estimate for the United States is about 32000-92000 m^3. If the majority of the facilities have only one such laboratory then the impacts will be small with the range of wastes being 7400-2800 m^3. On the other hand, they will be much higher should the majority have multiple laboratories.

Table 6.1

Estimates of Volumes of Radioactive Waste for Generic Laboratories

Laboratory Component	Waste Volumes for Generic Laboratories (m^3)				
	^{3}H	^{14}C	I	^{137}Cs	^{241}Am
Fume Hoods	0-8	0-4	0-4	0-4	0
Glove Boxes	0-3	0-1	1-4	0	4-8
Hot Cells	0	0	0	1.5-3	0
Benches	0-13.5	0-10	0-5	0-2	0-1
Floor Surfaces (tiles)	0-0.4	0-0.4	0-0.4	0-0.4	0-0.4
Ventilation Ductwork	3-5	3-5	3-5	3-5	5
Sinks	0	0-1	0	0	0
Cleaners, Waste	26-29	200	14	12	17-20
Misc. (8 drum)	0-1.7	0-1.7	0-1.7	0-1.7	0-1.7
TOTAL	29-61	23-43	18-29	16-28	26-36

Total range for all 5 laboratories: 110-200 m^3

Table 6.2

Volumes of Waste from Manufacturers and Suppliers
Per NRC Region

Region	No. of Facilities	Volume of Waste (m^3)		
		3 Laboratories	All 5 Laboratories	Combined Range
1	205	14400-27300	23000-41000	14400-41000
2	29	2000-3900	3200-5800	2000-5800
3	149	10400-19800	16400-29800	10400-29800
4	30	2100-4000	3300-6000	2100-6000
5	45	3200-6000	5000-9000	3200-9000
U.S. Totals	458	32100-61000	50900-91600	32100-91600

6.2 Estimates for Nuclear Pharmacies

Laboratories at nuclear pharmacies are usually small and mobile. Decontamination is conducted on a continual basis as a part of operations. Yet, all equipment has a limited useful life and, therefore, even at these facilities there will be some waste. Assuming that 2 fume hoods, ventilation ductwork, miscellaneous supplies and trash and cleaning solutions used in decontamination will be handled as radioactive waste, leads to an estimate that 2-15 m^3 (Table 6.3) of low-level waste will be generated at each of the approximately 100 facilities identified in the report. The total projection for the United States is only 200-1500 m^3, which seems quite small when compared to the facilities discussed in Section 6.1.

6.3 Conclusion

Waste volumes from individual facilities listed in this report will vary among facilities and will be dependent upon activities conducted at each, types and number of components at each, and site-specific radiological contamination. However, several general observations are possible. Radioisotope and radiopharmaceutical manufacturers will generally produce greater volumes of radioactive waste than will suppliers. Also, facilities producing or handling long-lived radionuclides will ordinarily have a larger radiological impact than those with short-lived isotopes. However, all of these should be within the range of the estimates given, 70 to 200 m^3 per facility; and all considered together should be within the range of about 32000-92000 m^3 nationally by the year 2000. The nuclear pharmacy industry will generate much smaller amounts of waste nationally with a volume of approximately 200-1500 m^3 for all facilities by the year 2000.

Table 6.3

Estimated Volume of Waste Resulting from Decommissioning a Nuclear Pharmacy

Laboratory Component	Waste Volume (m^3)	Comments
Hoods	0-8	assuming 2 hoods
Ventilation Ductwork	1-3	
Cleaning	1-2	6 to 12 208 liter (55 gal) drums
Misc.	0-2	0 to 10 208 liter (55 gal) drums
TOTAL	2-15	U.S. Total: 200-1450 m^3

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Bu81 Burlison, J.S., August 1981, "List of DOE Radioisotope Customers with Summary of Radioisotope Shipments, FY 1980," Prepared by Pacific Northwest Laboratory, Richland, Washington, for U.S. Department of Energy, PNL-3839.

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IAEA66 International Atomic Energy Agency, 1966, "Manual of Radioisotope Production," Technical Report Series No. 63. IAEA, Vienna.

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NCRP80 National Council on Radiation Protection and Measurements, 1980, "Management of Persons Accidentally Contaminated with Radionuclides," NCRP Report No. 65.

Nu78 United States Nuclear Regulatory Commission, December 1978, "Plan for Reevaluation of NRC Policy on Decommissioning of Nuclear Facilities," USNRC, Office of Standards Development, Washington, D.C., NUREG-0436, Revision 1.

Nu80 United States Nuclear Regulatory Commission, June 1980, "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material," USNRC, Division of Fuel Cycle and Material Safety, Washington, D.C.

Nu81 United States Nuclear Regulatory Commission, January 1981, "Draft Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities," NUREG-0586.

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RI78 Rockwell International et al., September 1978, "Preliminary Plan for Decommissioning of Department of Energy Radioactively Contaminated Surplus Facilities," Prepared by Rockwell International et al. for the United States Department of Energy, Washington, D.C., HCP/PO 701-01.

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Tu76 Tubis, Manuel, Walker Wolf, 1976, Radiopharmacy, (New York: John Wiley and Sons, Inc.).

USAEC74 United States Atomic Energy Commission, 1974, "The Nuclear Industry," WASH 1174-74.

USEPA79 United States Environmental Protection Agency, August 1979, "Radiological Impact Caused by Emissions of Radionuclides into Air in the United States," Preliminary Report, EPA 520/7-79-006.

USERDA75 United States Energy Research and Development Administration, September 1975, "Proceedings of the First Conference on Decontamination and Decommissioning (D&D) of ERDA Facilities," held at Idaho Falls, Idaho, August 19-21, 1975, CONF-750827.

APPENDIX A.

LIST OF RADIOISOTOPE AND RADIOPHARMACEUTICAL MANUFACTURERS AND SUPPLIERS

List of Radioisotope and Radiopharmaceutical Manufacturers and Suppliers

AAR Corporation
Aeronetics Div.
2100 Touhy Ave.
Elk Grove Village, IL 60007

Abbott Laboratories[b,c]
Radiopharmaceutical Products Div.
North Chicago, IL 60064

*Oak Ridge, TN 37830

*ACF Industries, Inc., Nuclear products, Erco Reactor Engineering Dept.
Washington, D.C.

Advanced Medical Systems, Inc.
1020 London Rd.
Cleveland, OH

*Aerojet-General Nucleonics, Reactor Development
San Ramon, CA

Aerojet Strategic
PO Box 15699C
Hwy. 50
Sacramento, CA

*Aeronautical Instrument & Radio Co.
234 Garibaldi Ave.
Lodi, NJ 07644

Aerotest Operations[a]
San Ramon, CA

Air Products and Chemicals Inc.
Houdry Laboratories
PO Box 427
Marcus Hook, PA 19061

Airco Inc.
Airco Industrial Gases Div. Rare & Specialty Gas Dept.
Union Landing Rd.
Riverton, NJ 08077

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* Retired or transferred licenses.

a. Principal producers of radiochemicals
b. Principal producers of radioimmunoassay reagents
c. Principal producers of radiopharmaceuticals

*Aldens Inc.
5000 W. Roosevelt Rd.
Chicago, IL 60607

Alfred I. DuPont Institute of the N
Research Div.
PO Box 269 Rockland Rd.
Wilmington, DE 19899

*Allen Products Co. Inc.
PO Box 2187 R.D. #3
Allenntown, PA 18001

Allied Technology Inc.
Manufacturing
6104 Poe Ave.
Dayton, OH 45414

*Allis Chalmers Manufacturing Co.
1126 S. 70th St.
Milwaukee, WI 53201

*Alpha Diagnostics
37 Kings Rd.
Madison, NJ 07940

*American Biomedical Corp.
3408 Industrial Parkway
Jeffersonville, IN 47130

*American Nuclear Company Plant
Clinton, TN

American Nuclear Diagnostics Inc.
2715 Bissonnet St., Suite 105
Houston, TX 77005

American Atomics Corp.
425 S. Plumer Ave.
Tucson, AZ 85719

*American Cyanimid Co., Pharmacological Res. Dept.
Pearl River, NY

American Nuclear Products
1232 E. Commercial
Springfield, MO 64803

American Radiochemical Corp.[a]
Sanford, FL

Amersham/Searle[a,b,c]
2636 Clearbrook Dr.
Arlington Heights, IL 60005

Ames Company[a,c]
Division of Miles Laboratory
Elkhart, IN

Amicon Corp.
25 Hartwell Ave.
Lexington, MA 02173

*Analytical Instrument Development
Rt. 41 & Newark Rd.
Avondale, PA 19311

Applied Health Physics, Inc.
2986 Industrial Blvd.
Bethel Park, PA 15102

Applied Science Labs, Inc.
139 N. Gill St.
State College, PA 16801

*Arabian American Oil Co.
505 Park Ave.
New York, NY 10022

ARCO Medical Products Co.
PO Box 546
Leechburg, PA 15656

*ARNO Adhesive Tape Inc.
US and Ohio St.
Michigan City, IN 46360

Arthur D. Little Inc.
15 Acorn Park
Cambridge, MA 02140

*ATCOR Inc.
Park Mall
Peekskill, NY 10566

Atlantic Richfield Company
260 S. Broad St.
Philadelphia, PA

*Atomchem Corp.
1 E. Main St.
Bay Shore, NY 11706

Automation Industries, Inc.
Kimberton Rd., Rt. #113S
Phoenixville, PA

*AVCO Corp.
Lycoming Div.
550 S. Main St.
Stratford, CT 06497

AVCO Everett Research Laboratory Inc.
2385 Revere Beach Parkway
Everett, MA 02149

Babcock & Wilcos Co. (The)
609 N. Warren Ave.
Apollo, PA 15613

Baird-Atomic, Inc.
125 Middlesex Tpk.
Bedford, MA 01730
*Cambridge, MA

Baker Industries Inc.
8 Ridgedale Ave.
Cedar Knolls, NJ 07927

Ball Packaging Products Inc.
1509 S. Macedonia Ave.
Muncie, IN 47302

Baltimore Gas & Electric Co.
Gas and Electric Building
Baltimore, MD 21203

Barbara Kent, Ph.D.
Mount Desert Island Bio. Lab
Salisburg Cove, ME 04672

*Battelle Memorial Institute
505 King Avenue
Columbus, OH

Bayless Pathology Associates Inc.
Severance Medical Arts Bldg.
5 Severance Circle, Suite #804
Cleveland Heights, OH 44118

Beckman Instruments Inc.
2500 Harbor Blvd.
*Fullerton, CA 92634

US Hwy. 22 at Summit Rd.
Mountainside, NJ 07091

7262 Washington Ave. South
Eden Prairie, MN 55344

*4815 W. 77th St., Suite 112
Minneapolis, MN 55435

7360 N. Lincoln Ave.
Lincolnwood, IL 60646

*Bemis Co. Inc.
315-27th Ave. NE
Minneapolis, MN 55418

Bendix Corp. (The)
Production Dept.
721 Springfield St.
*Dayton, OH 45403

*Process Instruments Div.
Route #1 Box 44
Fults, IL 62244

Berkley Engineering & Equipment Co.
PO Box 3856, 564 South St.
Honolulu, HI 96812

*Beta Laboratories, Inc.
Philadelphia, PA

Bicron Corp.
12345 Kinsman Rd.
Newbury, OH 44065

Bio-Chem Inc.
21174 Bridge St.
Southfield, MI 48075

Bio-Chemical & Nuclear Corp.[a]
Burbank, CA

Bionucleonics Inc.
753 Boulevard
Kenilworth, NJ 07033

Bio-Rad Laboratories[a]
Berkeley, CA

Bio-Science Laboratories
Detroit Branch
24469 Indoplex Circle
Farmington Hills, MI 48024

St. Louis Branch
1530 Page INdustrial Blvd.
Overland, MO 63132

*Bird Well Surveys Radioactive-Tracer Dept.
Bradford, PA

Blake Equipment Corp.
110 Route 4
Englewood, NJ 07631

*Blood Alliance
2191 E. 19th St.
Cleveland, OH 44115

Blood Systems Inc.
6401 E. Thomas Rd.
Scottsdale, AZ 85252

Boehringer Ingelheim Ltd.
PO Box 368
Ridgefield, CT 06877

*Boeing Company (The)
Military Aircraft Systems Div.
Wichita Branch
Wichita, KA 67210

*Bomac Laboratories, Inc.
Beverly, MA

Boston Edison Co.
Pilgrim Div.
800 Boylston St.
Boston, MA 02199

*Boston Medical Laboratory
19 Bay State Rd.
Boston, MA 02215

Branding Assocation of the United STates
PO Box 73
Midland, TX 79701

*Budd Co.; Gamma Corp.
Philadelphia, PA

Burroughs Corp.
PO Box 1226
Plains Field, NJ 07061

*CBS-Hytron
Newburyport, MA

C.P. Clare Co.
Div. of General Instrument Corp.
3101 W. Pratt Blvd.
Chicago, IL 60645

*C.H.P. Allen Brodsky, Sc.D.
2047 Brookfield Dr.
Pittsburgh, PA 15243

Calatomic, Inc.[a]
Los Alamos, CA

California Radiochemicals, Inc.[a]
Los Angeles, CA

*Cal-Rad, Inc., Organic Chemistry Dept.
Burbank, CA

Cambridge Nuclear Radiopharmaceuticals[a,c]
Radiopharmaceutical Manufacturing
PO Box 528
Princeton, NJ 08540

Canberra Industries
Detector Dept.
45 Gracey Ave.
Meriden, CT 06450

Capintec Instruments Inc.
540 Alpha Drive.
Pittsburgh, PA 15238

*Central Electronics Manufacturing Co.
Danville, NJ

Caterpillar Tractor Co.
Mapleton, IL 61547

Central Laboratory
57 W. Jefferson St.
Joliet, IL 60431

Cetron Electronic Corp.
715 Hamilton St.
Geneva, IL 60134

*Check-Up Medical Laboratory
Multiphasic Laboratory
13250 Northend
Oak Park, MI 48223

Cherry Electrical Products, Corp.
3600 Sunset Ave.
Waukegan, IL 60085

Chevron Research Co.
576 Standard Ave.
Richmond, CA 94802

CIBA Corp.
CIBA Pharmaceutical Div.
556 Morris Ave.
Summit, NJ 07901

CIBA-GEIGY Corp.
Pharmaceutical Div.
Saw Mill River Rd.
Ardsley, NY 10502

CIS Radiopharmaceuticals Inc.
5 De Angelo Dr.
Bedford, MA 01730

*Clinton Corn Processing Co.
A Division of Standard Brands Inc.
1251 Beaver Channel Pkwy.
Clinton, IA 52732

*Collins Radio Co.
5225 C Ave., NE
Cedar Rapids, IA 52406

Columbia Medical Laboratory
1475 Barnum Ave.
Bridgeport, CT 06610

Combustion Engineering Co.
Power Systems Group
1000 Prospect Hill Rd.
Windsor, CT 06095

Conrac Corp.
Rixon/Firemark Inc. Div.
9100 W. Belmont Ave.
Franklin Park, IL 60131

*Control System Inc.
395 Lawndale Dr.
Salt Lake City, UT 84115

Cook Electric Co.
6201 Oakton St.
Morton Grove, IL 60053

Corning Glass Works
Biological Products Group
Medfield, MA 02052

Corning Glass Div.
333 Coney St.
Walpole, MA 02032

*Cox Heart Institute
3525 Southern Blvd.
Kettering, OH 45429

Cryogenic Rare Gas Laboratories Inc.
730 South 13th St.
Newark, NJ 07103

Curtis Nuclear Corp.[a,c]
Los Angeles, CA

Curtiss-Wright Corp.
*East Paterson, NJ

*Carlstadt, NJ

*DACOR Corporation
161 Northfield Rd.
Northfield, IL 60093

Dale Electronics Inc.
E. HIghway 50, PO Box 180
Yankton, SD 57078

Damon
Damon Diagnostics Div.
115 Fourth Ave.
Needham Heights, MA 02194

Damon Medical Laboratory Inc.
115 Fourth Ave.
Needham Heights, MA 02194

Dearborn Clinical Laboratories
2120 Monroe St.
Dearborn, MI 48124

Deluca, Jr., Ph.D., Paul M.
Medical Physics Section Dept. of Radiology
University of Wisconsin
Madison, WI 53706

Detroit Bio Medical Lab Inc.
20851 West & Seven Mile Rd.
Detroit, MI 48219

Dhom Products, Ltd.[a,c]
North Hollywood, CA

Diagnostic Isotopes Inc.
225 Billeville Ave.
Bloomfield, NJ 07003

Upper Saddle River, NJ[c]

Diagnostic Management, Inc.
2233 University Ave.
St. Paul, MN 55114

Diagnostic Photon Corp.
Pridco Industrial Park
PO Box 526 Carr. 992 KM 03-Blg.5
Luquillu, PR 00673

Diamond Shamrock Health Sciences Inc.
11001 Cedar Ave.
Cleveland, OH 44106

Diaz, Jose Clemente Pacheco
Box 3689 Bayamon Gardens Sta.
Bayamon, PR 00620

Dosimeter Corp. of America
Engineering and Production Dept.
6106 Interstate Circle
Cincinnati, OH 45242

*Douglas Aircraft Co., Inc.
Santa Monica, CA

*Dow Chemical Co.
Hanging Rock Plant
Ironton, OH 45638

*Building 1602
Midland, MI 48640

*Dresser Research Ind., Inc.
Tulsa, OK (Cleared by Tracerlab and OK Dept. of Health)
Decontaminated*

DRG International Inc.
217 Elmer St.
Westfield, NJ 07080

Durlacher, James
6741 Allisonville Rd.
Indianapolis, IN 46320

Dynatech Laboratories Inc.
Research & Clinical Applications Laboratory
900 Slaters Lane
Alexandria, VA 22314

*E&A Engineering Inc.
Old Santa Fe Trail
PO Box 598
Santa Fe, NM 87501

EG&G Inc.
35 Congress St.
Salem, MA 01970

*E.I. DuPont de Nemours and Co., Inc.
Montague, MI

*E.R. Johnson Associates Inc.
Suite 312, Barr Building
Washington, DC 20016

E.R. Squibb and Sons, Inc.[b,c]
Squibb Institute for Medical Research
Georges Rd.
New Brunswick, NJ 08903

14447 Firestone
LaMirada, CA 90638

Eberline Instrument Corp.
PO Box 2108
Airport Rd.
Santa Fe, NM 87501

*Edwards Co. Inc.
90 Connecticut Ave.
Norwalk, CT 06856

*Electronic Automation Sys., Inc.
2957 Alt Blvd.
Grand Island, NY 14072

*Electronics and Manufacturing Corp.
840 N. Henry St.
Alexandria, VA 22313

*Electrons Co.
65 Passaic Ave.
Fairfield, NJ 07006

*El-Tronics, Inc. (Became Div. of Pigsecki Aircraft 7/28/59)
Mayfield, PA

*Empire Xperimental Corp.
Brooklyn, NY

Endocrine Antibodies Inc.
217 Read St.
Portland, ME 04103

*Entronic Corp.
4348 Riverline Drive
Earth City, MO 63045

*Environmental Devices Corp.
13 Marconi Lane
Marion, MA 02738

*EPCO Services, Inc.
7760 W. Devon Ave.
Chicago, IL 60631

Exxon Research and Engineering Corp.
PO Box 51
Linden, NJ 07036

Fairchild Camera & Instrument Corp.
750 Bloomfield Ave.
Clifton, NJ 07015

Fife Corp.
PO Box 26508
Oklahoma City, OK 73126

Fischer Technology Inc.
750 Marshall Phelps Rd.
Windsor, CT 06095

Fort Wayne Medical Laboratory Corp.
Radioisotope Dept.
347 W. Berry St.
Fort Wayne, IN 46802

*Friend Well Surveys
PO Box 216, 411 East Main
Fairfield, IL 62837

*Gamewell Corp. (The)
7 Industrial Park Rd.
Medway, MA 02053

Gammaceutics
3120 Crow Canyon Rd.
San Ramon, CA 91406

Gamma Diagnostic Laboratories
Manufacturing, Quality Control, Research and Development
PO Box 1349
Attleboro Falls, MA 02763

*Gamma Industries - Port Norris[a]
Div. of Nuclear Systems Inc.
1 Gamma Dr.
*Port Norris, NJ 08349

Houston, TX

Baton Rouge, LA

*Gamma Products Co.
922 Noel Drive
Mundelfin, IL 60060

*Gammie Nuclear Service Co., Inc.
3737 No. Mt. Prospect Rd.
Franklin Park, IL 60131

*Geib Elston Frost Professional Assoc.
2805 S. 5th St.
Rapid City, SD 57701

*General Dynamics Corp.
San Diego, CA

General Electric Co.
Space Division Valley Forge Space Tech. Center
PO Box 8555
*Philadelphia, PA 19101

*Bridgeport, CT 06602

Nela Park
Cleveland, OH 44112

*San Jose, CA

*Schenectady, NY

Pleasanton, CA[a]

*Euclid, OH

*Fort Wayne, IN

4855 Electric Ave.
Milwaukee, WI 53201

Vallecitos, CA

Housewares Business Div.
Homer Ave.
*Ashland, MA 01721

*General Instrument Corp.
Signalite Div.
1933 Heck Ave.
Neptune, NJ 07753

*General Motors Corp.
Detroit, MI

*Georgia Power Co.
270 Peachtree St., NW
Atlanta, GA 30302

Georgia-Pacific Corp. (The)
125 N. River St.
Franklin, OH 45005

Glow-Lite Corp.
PO Box 698
Pauls Valley, OK 73075

Gollob Analytical Service Corp.
Radiochemistry Dept. Div. of Will Ross Inc.
47 Industrial Rd.
Berkeley Heights, NJ 07922

Graviner Inc.
1121 Bristol Rd.
Mountainside, NJ 07092

Great Lakes Clinical Laboratory
311 N. Clippert St.
Lansing, MI

Group Health Assocation
2121 Pennsylvania Ave., NW
Washington, DC 20037

GTE Sylvania Inc.
3101 Pleasant Valley Blvd.
Altoona, PA 16603

*100 Endicott St.
Danvers, MA 01923

*Gulf & Western Mfg. Co.
91 Bartlett St.
Marlborough, MA 01752

*Hadley Weld Plant
Saegertown Components Div.
RD 2, PO Box 77
Hadley, PA 16130

*Hamilton Standard Div.
Div. United Aircraft Corp.
Bradley Field
Windsor Locks, CT 06096

Harshaw Chemical Co. (The)
6801 Cochran Rd.
Solon, OH 44139

*Hazleton Research Animals, Inc.
PO Box 5
Cumberland, VA 23040

Health Physics Associates, Ltd.
3304 Commercial Ave.
Northbrook, IL 60062

*Hewlett E. Jr. Melton, Ph.D.
Dept. of Pathology Medical College of Wisconsin
8700 W. Wisconsin Ave.
Milwaukee, WI 53226

Hewlett Packard Co.
330 Progress Rd.
*Dayton, OH 45449

Avondall Div.
Route 41 and Starr Rd.
Avondale, PA 19311

148 Weldon Pkwy.
Maryland Heights, MD 63043

Hoffmann-LaRoche Inc.
340 Kingsland St.
Nutley, NJ 07110

Honeywell Inc.
Manufacturing
2701 Fourth Ave. South
Minneapolis, MN 55408

1500 W. Dundee Rd.
Arlington Heights, IL 60004

Bloomington, MN 55420

600 2nd St., NE
Hopkins, MN

*Hughes Aircraft Co.
Building 21
Los Angeles, CA 90009

ICN Pharmaceuticals
2727 Campus Dr.
Irvine, CA 92664

ImajInternational, Inc.[C]
(Nuclear Medicine Div. of Allergan Pharmaceuticals)
Irvine, CA

Immuno Assay Corp.
25050 Ford Rd.
Dearborn Heights, MI 48127

Immuno Nuclear Corp.
6303 Osgood Ave., North
Stillwater, MN 55082

In-Val-Co
A Div. of Combustion Engineering Inc.
PO Box 556
Tulsa, OK 74101

INDEV Control System Inc.
PO Box 686, 5 Burnside St.
Bristol, RI 02809

Industrial Nuclear Co. Inc.[c]
9641 Lackland Rd.
Overland, MO 63114

Industrial Nucleonics Corp.
650 Ackerman Rd.
Columbus, OH 43202

Industrial Reactor Laboratories, Inc.
Plainsboro, NJ

*Industrial Testing Company
8407 Atlantic Ave.
Bell, CA

*Inolex Pharmaceutical
2600 Bond St.
Glenwood, IL 60466

*Integreated Industrial Systems
25 Wallace St.
Wallingford, CT 06492

Intertex Corp.
3 Strathmore Rd.
Natick, MA 02154

International Chemical and Nuclear[a]
Chemical & Radioisotopes Div.
2727 Campus Dr.
Irvine, CA 92664

Interstate Blood Bank of Chicago, Inc.
3324 W. Lawrence Ave.
Chicago, IL 60625

Ion Track Instruments Inc.
Three A St.
Burlington, MA 01803

Isolab, Inc.[a]
Akron, OH

Iso-Med Inc.[c]
(Div. of New England Nuclear)
Hawthorne, CA

Isotec Corp.
1029 Senate Dr.
Centerville, OH 45459

*Isotope Industries Inc.
15375 Brookpark Rd.
Brookpark, OH 44142

Isotopes Measurements Laboratories
3304 Commercial Avenue
Northbrook, IL 60062

*Isotope Products, Inc.
Buffalo, NY

*Isotopes, Inc.
Westwood, NJ

*Isotopes Specialties Co., Inc.
Burbank, CA

Isovac Engineering Inc.
932 Grand Central Ave.
Glendale, CA 91201

*J.L. Shepherd and Associates
703 S. Pacific Ave.
Glendale, CA 91204

J.T. Baker Chemical Co.
Research Dept.
222 Red School Lane
Phillipsburg, NJ 08865

*Jefferson Research Lab., Inc.
Charlottesville, VA

Jemco Engineering Co.
400 E. Wapella St.
Minooka, IL 60447

*John A. Kerin
350 N. Roselle Road
Roselle, IL 60172

John C. Haynes Co.
800 Hebron Rd.
Newark, OH 43055

John E. Hand & Sons Co.
Beechwood Ave. & Birch St.
Cherry Hill, NJ 08034

Kaman Nuclear Division of Kaman Sci.
Kaman Nuclear Division
1700 Garden of the Gods Rd.
Colorado Springs, CO 80907

Kay-Ray Inc.
516 W. Campus Dr.
Arlington Heights, IL 60004

*L.W. Denney Chem-Medical Corp.
8501 Zionsville Rd.
Indianapolis, IN 46268

Laboratory Associates inc.
1200 N. Lasalle Street
Chicago, IL 60610

Lake Center Industries
111 Market St.
Winona, MN 55987

*Lancet Laboratories
3166 Des Plaines Ave.
Des Plaines, IL 60018

*Landis & Gyr Inc.
45 W. 45th St.
New York, NY 10036

Lear Stegler Inc.
4141 Eastern Ave., SE
Grand Rapids, MI 49508

Lederle Diagnostics of PR
PO Box AC Pueblo Station
Carolina, PR 00630

Libby McNeill & Libby
Research & Product Development
1800 W. 119th St.
Chicago, IL 60643

LFE Corp.
Process Control Div.
1601 Trapelo Rd.
Waltham, MA 02154

*Litton Bionetics Inc.
5516 Nicholson Lane
Kensington, MD 20795

Lockheed Aricraft Corp.
Marietta, GA

*Ludlum Measurements Inc.
Corner of Washington & Jeffers
Haymarket, VA 22069

Luminous Processes Inc.
161 East 42nd St.
New York, NY 10017

*Maine Yankee Atomic Power Co.
9 Green St.
Augusta, ME 04330

Mallinckrodt Inc.[a,c]
675 Brown Rd.
St. Louis, MO 63147

*Mallinckrodt/Nuclear
463 Barell St.
Carlstadt, NJ 07072

Mallinckrodt/Nuclear
Box 10172 Lambert Field
St. Louis, MO 63145

Malone Electronic Service Co.
949 Havensport Dr.
Cincinnati, OH 45240

*Manning Lab
Portsmouth, NH

Marshall Field & Co.
111 Northstate St.
Chicago, IL 60690

Mason-Barron Laboratories Inc.
4720 W. Montrose Ave.
Chicago, IL 60641

Matheson Gas Products
Matheson Gas Products Div.
932 Paterson Plank Rd.
E. Rutherford, NJ 07073

*McDonnell Douglas Astronautics Comp.
Donald W. Douglas Laboratories
2955 George Washington Way
Richland, WA 99352

McNeil Laboratories Inc.
Camp Hill Rd.
Fort Washington, PA 19034

Mead Johnson and Co.
Mead Johnson Research Center
Evansville, IN 47721

Medical Research Foundation, Inc. (The)
101 Cleveland Professional Bldg.
2788 Bayard St.
East Point, GA 30344

Medi-Physics Inc.
900 Durham Ave.
S. Plainfield, NJ 07080

5855 Christie Ave.[C]
Emeryville, CA 94608

3350 N. Ridge
Arlington Heights, IL 60004

1141 Airway St.
Glendale, CA 91201

*Merck, Sharp and Dohme Res. labs
West Point, PA

Metpath Inc.
One Malcomb Ave.
Teterboro, NJ 07608

Metropolitan Enterprises Inc.
PO Box 60468
Oklahoma City, OK 73106

Micro-Dynamics Inc.
10 Sonar Dr.
Woburn, MA 01801

Microwave Associates Inc.
South Ave.
Burlington, MA 01803

Midwest Research Institute
425 Volker Blvd.
Kansas City, MO 64110

Miles Laboratories Inc.
400 Morgan Lane
West Haven, CT 06516

*4718 Yender Ave.
Lisle, IL 60532

195 W. Birch
Kankakee, IL 60901

1127 Myrtle St.[a]
Elkhart, IN 46514

Minnesota Mining and Manufacturing
3M Center
St. Paul, MN 55101

Moisan Assoc.
109 Congress St.
Lowell, MA 01852

Molins Machine Co.
3900 Carolina Ave.
Richmond, VA 23222

Monsanto Research Corp.[a]
1515 Nicholas Rd.
PO Box 8
Dayton, OH

*Murray Machinery Inc.
1002-1024 Third St.
Wausau, WI 54401

*Nalco Chemical Co.
Radiochemical Dept.
6216 West 66th Place
Chicago, IL

New England Medical Laboratories Inc.
1750 Washington St.
Holliston, MA 01746

New England Nuclear Corp.
549 Albany St.
Boston, MA 02118

Medical Diagnostic
575 Albany St.
Boston, MA 02118

N. Billerica, MA[a,c]

*Nichem, INc.
PO Box 5737
Bethesda, MD

Nittan Corp.
1299 Rand Rd.
Des Plaines, IL 60016

NL Industries Inc.
Nuclear Metals Div. Wilmington Plant
Foot of West St.
Wilmington, DE 19801

Norland Instruments
Div. of Norland Corp.
Rte. 4, Norland Dr.
Fort Atkinson, WI 53538

Norris Industries Inc.
Hesse-Eastern Div.
1123 Pearl St.
Brockton, MA 02401

North Jersey Blood Center
45 S. Grove St.
E. Orange, NJ 07018

Northern States Power Co.
Nuclear Support Services Dept.
414 Nicollet Mall
Minneapolis, MN 55401

*Nuclear Aids Corp.
Chicago, IL

Nuclear Associates, Inc.[a]
Westburg, NY

*Nuclear Chemical Co.; Isotope Chemical Co.
Chicago, IL

Nuclear Consultants Inc.
*St. Louis, MO

*Long Island City, NY

*Nuclear Corp. of America; Radioactive Products, Inc.
Ferndale, MI

*Nuclear Dev. Corp. of America
White Plains, NY

Nuclear Diagnostic Laboratories Inc.
950 W. Mockingbird Lane
Dallas, TX 75247

Nuclear Dynamics[a]
Elmonte, CA

*Nuclear Endocrine Laboratories Inte
10623 Chester Ave.
Cleveland, OH 44106

*Nuclear Engineering Co. Inc.
PO Box 594
Walnut Creek, CA 94597

Nuclear Equipment Chemical Corp.[a]
Farmingdale, NY

Nuclear Instruments Corp.
2345 W. Mill Rd.
Milwaukee, WI 53209

*Nuclear Laundry Rental Service Inc.
14th and Gaskill
Jeannette, PA 15644

Nuclear Medex Inc.
330 Stephen Dr.
Toms River, NJ 08753

Nuclear Medical Labs, Inc.[a]
Dallas, TX

Nuclear Medical Services, Inc.
16140 Runnymede St.
Van Nuys, CA 91406

Nuclear Metals
2229 Main St.
Concord, MA

Nuclear Research Corp.
Denville Nuclear Div.
2 Richmond Place
Denville, NJ 07834

1105 Industrial Hwy.
Southampton, PA 18966

Nuclear Supply Co.
9403 Fresno Rd.
Bethesda, MD

*Nuclear Systems, Div. of Budd Co.
Philadelphia, PA

Nucleus (The)
461 Laboratory Rd.
Oak Ridge, TN 37830

*Ohmart Corp. (The)
4241 Allendorf Dr.
Cincinnati, OH 45209

*Oklahoma Testing Labs
310 N. Kelin
Oklahoma City, OK 73106

Omni Research Inc.
Caribbean Research Laboratoriees
PO Box 1156
San German, PR 00753

Omni-Wave Electronics Corp.
Blackburn Industrial Park
PO Box 660
Gloucester, MA 01930

*Orlando Research Inc.
Orlando, FL

P-L Biochemicals Inc.
1037 W. McKinley Ave.
Milwaukee, WI 53205

*Pacific Isotopes, Inc.; Portland Med. Center, Isotopes Supply
Portland, OR

Packard Instrument Co. Inc.
2200 Warrenville Rd.
Downers Grove, IL 60515

Pan American World Airways Inc.
Aerospace Services Div.
Pan Am 9, OMEHS
Kennedy Space Center, FL 32899

Panametrics Inc.
221 Crescent St.
Waltham, MA 02154

Panel Technology Inc. (PANTEK)
Mifflin County Ind. Park Rt. 2
Lewistown, PA 17044

*Parkwell Labs, Inc.
429 North High St.
Croton, OH 43013

Bldg. 374
Ft. Belvoir, VA

Pathfinder Laboratires Inc.
11542 Fort Nims Dr.
Maryland Heights, MO 63141

*Paul King Co.
PO Box 15827
Tulsa, OK 74115

Perkin-Elmer Corp. (The)
Maine Ave.
Norwalk, CT 06852

Permagrain Products Inc.
22 West State St.
Media, PA

Pfizer & Co. Inc.
Groton, CT

*Maywood, NJ

*Pharmacia Inc.
800 Centennial Ave.
Piscataway, NJ 08854

*Philco-Ford Corp.
Union Meeting Rd.
Blue Bell, PA 19422

*Philip P. Benjamin Ph.D.
DBA Medi-Nuclear Institute
6218 Clayton Ave.
St. Louis, MO 63139

Philips Medical System Inc.
710 Bridgeport Ave.
Shelton, CT 06484

Picker Corp.
Picker X-Ray Mfg. Division
595 Miner Rd.
Cleveland, OH 44143

1020 London Rd.
Cleveland, OH 44143

Nuclear & Ultrasound
12 Clintonville Rd.
Northford, CT 06472

Pittway Corp.
BRK Electronics Div.
780 McClure Ave.
Aurora, IL 60507

Porter Marine Inc.
PO Box 278
Blue Bell, PA 19422

*Precision Scientific Co.
3737 W. Cortland St.
Chicago, IL 60647

*Pressure Chemical Co.
3419-25 Smallman St.
Pittsburgh, PA 15201

Proctor and Gamble Dist. Co.
PO Box 171
Cincinnati, OH 45201

Quality Products Inc.
Charlotte Amalie
St. Thomas, VI 00801

R.A. Miller Electronics Corp.
14500 168th Ave.
Grand Haven, MI 49417

*Radiation Equipment and Accessories Corp.
Lynbrook, NY

Radiation Management Corporation
Science Center Bldg. #2
3508 Market St.
Philadelphia, PA 19104

*Radiation Products, Co.
Dallas, TX

*Radiation Medical Service
405 Chandler St.
Tewksbury, MA 01876

*Radiation Research Corp.
New York, NY

*Radiological Research Inst., Inc.
Denver, CO

*Radionics, INc.
Lafayette and Water Sts.
Norristown, PA

Radtrace Co.
3821 S. Teakwood St.
Santa Ana, CA 92707

RadX Corp.
1390 West Belt North
Houston, TX 77043

*Ralston Purina Co.
900 Checkerboard Square
St. Louis, MO 63188

Rawdon Myers Inc.
PO Box 44216
Cincinnati, OH 45216

*Raychem Labs
Elmsford, NY

*RCA Corporation
2000 Clements Bridge Rd.
Deptford, NJ 08096

Realtime Corporation
Receiving, Warehouse and Shipping Service Dept.
21 N. Skokie
Lake Bluff, IL 60044

*Redco Nucleonics Inc.
181 Main St.
Danbury, CT 06810

*Reitzel Assoc.
10 Kendall Place
Boylston, MA 01505

Republic Industries Inc.
Division of Dor-o-Matic
7350 W. Wilson Ave.
Chicago, IL 60656

Research Appliance Co.
Rt. 8 and Craighead Rd.
*Allison Park, PA 15101

*Rte. 8
Gibsonia, PA 15044

Research Institute of Oncology
9150 Crawford Ave.
Skokie, IL 60076

Research Products International Corp.
2692 Delta Lane
Elk Grove, IL 60007

Research Specialties Co.
195 Nassau St.
Princeton, NJ

*Reuter-Stokes Inc.
18530 S. Miles Pkwy.
Cleveland, OH 44128

Reynolds Industries Inc.
5005 McConnell Ave.
Los Angeles, CA 90066

RIA Products Inc.
97 Beaver St.
Waltham, MA 02154

*Richmond Metropolitan Blood Services
4005 W. Broad St.
Richmond, VA 23230

*Robert B. Carroll Ph.D. Chemical Cons
127 Doubling Rd.
Greenwich, CT 06831

Roche Clinical Laboratories
5 Johnson Dr.
Raritan, NJ 08869

*Robertshaw Controls Co.
Santa Ana Freeway at Euclid St.
Anaheim, CA 92803

Rupp & Bowman Co. (The)
24505 Indoplex Circle
Farmington, MI 48018

Safety Light Corp.
4150-A Old Berwick Rd.
Bloomsburg, PA

Sandoz Inc.
391 Chiketa Way Research Park
Salt Lake City, UT 84106

*Sargent-Welch Scientific Co.
7300 N. Linder Ave.
Skokie, IL 60076

Schlumberger Technology Co.
Schlumberger-Doll Research Center
Old Quarry Rd.
Ridgefield, CT 06877

Schwarz/Mann[a,b]
Div. of Becton
Dickinson & Co.
Orangeburg, NY

*Schwarz Laboratories, Inc.; Schwarz BioResearch Inc.
Mount Vernon, NY

*Scott and Livermore Radioactivity Consultants
Portland, OR

Sea Farm Research Foundation Inc.
60 Carlton Rd.
Waban, MA 02168

Seaman Nuclear Corp.
3846 W. Wisconsin Ave.
Milwaukee, WI 53208

Searle Diagnostics Inc.
2000 Nuclear Drive.
Des Plaines, IL 60018

Sensor-Tec Inc.
9401 W. Highway 42 PO Box
Goshen, KY 40026

Serono Laboratories Inc.
11 Brooks Dr.
Braintree, MA 02184

Siemens Medical of America Inc.
X-Ray Div.
685 Liberty ave.
Union, NJ 07083

Six States Engineering Inc.
201 Commonwealth Ave.
Springfield, VT 05156

*Smith, Kline, and French Laboratories
Philadelphia, PA

Soiltest Inc.
Nuclear Instruments Div.
524 S. Boulevard
Baraboo, WI 53913

Subsidiary of CENCO Instrument Corp.
2205 Lee St.
Evanston, IL 60202

Source Production and Equipment Co., Inc.
625 Oxley St.
Kenner, LA 70062

*Sperry Rand Corp.
Sperry Marine Systems
Route 29 North
Charlottesville, VA 22901

Sybron Corp.
Taylor Instrument Industrionics Div.
72 Eyland Ave.
Succasunna, NJ 07876

*Technical Assistance Corp.
2102 2nd Ave., North
Billings, MT 59101

Technical Equipment Marketing & Sal
10100 White Ave.
Clinton, MD 20735

Technical Operations Inc.
Northwest Industrial Park
Burlington, MA 01803

Technicare Inc.
29100 Aurora Rd.
Solon, OH 44139

Technicon Corp.
Quality Control
Box 307, Rte. 11 South
Middletown, VA 22645

*Teledyne Isotopes[a]
Palo Alto, CA

*Terry Sallee
Philips Roxane Inc.
26211 North Belt Highway
St. Joseph, MO 64502

Test Equipment Distributors, Inc.
18711 John R
Detroit, MI 48203

*Texas Nuclear Corp.; Austin Nuclear Corp.
Austin, TX

Texas Nuclear Division
PO Box 9267
Austin, TX 78766

Nuclear Chicago Corp.
9101 Highway 183
Austin, TX 78756

TFI Corporation
NDT Products Div.
870 First Ave.
West Haven, CT 06516

TII Industries Inc.
PO Box 433
Toa Alta, PR 00758

Timex Corp.
Park Rd. Extension
Waterbury, CT 06720

*Tracerlab, Inc.
Houston, TX

Travenol Laboratories
Hyland Division
Rte. 120 & Wilson Rd.
Round Lake, IL 60073

Clinical Assays Div.
620 Memorial Drive
Cambridge, MA 02130

TRC-Research Corporation of New E
125 Silas Deane Highway
Wethersfield, CT 06109

Tyco Laboratories Inc.
General Nucleonics Div.
2811 Metropolitan Place
Pomona, CA 91767

Union Carbide Corporation
Consumer Products Div.
401 Gage St.
*Bennington, VT 05201

Chemicals & Plastics - Measurement and Control Technology
PO Box 8361
South Charleston, WV 25303

*Tuxedo, NY 10987

*Linden, NJ 07037

*United Medical Laboratory Inc.
8 S. Michigan Ave.
Chicago, IL 60603

*United Shoe Machinery Corp.
Balch St.
Beverly, MA 01915

United States Radium Corp.
4150 Old Berwick Rd.
Bloomsburg, PA 17815

United States Steel Corp.
Clairton Works
*Clairton, PA 15025

600 Grant St.
Pittsburgh, PA 15230

Upjohn Co.
Kalamazoo, MI

United Technologies
Hamilton Standard Div.
Bradley Field Rd.
Windsor Locks, CT 06096

Sikorsky Aircraft Div.
North Main St.
Stratford, CT 06602

University of California
Crocker Nuclear Labs
Davis, CA

Varian Associates
Vacuum Div.
121 Hartwell Ave.
*Lexington, MA 02173

National Electronics Div.
Keslinger Rd.
Geneva, IL 60134

*Ventrex Laboratories Inc.
217 Read St.
Portland, ME 04103

Beverly, MA 01915

*Vermont Yankee Nuclear Power Corp.
77 Grove St.
Rutland, VT 05701

Victoreen Inc.
Victoreen Instrument Div.
10101 Woodland Ave.
Cleveland, OH 44104

Virgo Reagents[b]
Electro-Nucleonics Lab
Bethesda, MD

Vitreous State Products Co. Inc.
175 DuPont Drive.
Providence, RI 02907

*Volk Radiochemical Co.
Chicago, IL

*W and W Laboratories
158 Main St.
Matawan, NJ 07747

*Walter Kidde & Co. Inc.
Fire Alert Co. Div.
400 Main St.
Ashland, MA 01721

Waltham Compass Corp.
609 Main St.
Waltham, MA 02154

Warner Lambert Research Institute
170 Tuber Rd.
Morris Plains, NJ

Warren-Teed Pharmaceuticals, Inc.
(Rohm and Haas Co.)
582 W. Goodale St.
Columbus, OH 43215

*WC Sales Inc.
R.D. 2, Country Club Rd.
Easton, PA 18042

Western Electric Co.
777 North Blue Pky.
Lee's Summit, MO 64063

*Westgate Laboratory of Pathology Inc.
3301 W. Central Arcade 9B
Toledo, OH 43606

*Westinghouse Electric Corp.
Cheswick, PA 15024

3 Gateway Center, Box 2278
*Pittsburgh, PA 15230

*Weston Instruments Inc.
614 Frelinghuysen Ave.
Newark, NJ 07114

Wing Corp.
215 Highland Ave.
Westmont, NJ 08108

Wm. B. Johnson & Associates Inc.
-Engineering Dept.
Montville, NJ 07045

*Workman Developments Inc.
1741 Woodvale Rd.
Charleston, WV 25314

Worthington Biochemical Corp.[b]
Freehold, NJ

*Wyle Laboratories
3200 Magruder Blvd.
Hampton, VA 23666

APPENDIX B.

NUCLEAR PHARMACIES IN THE UNITED STATES

Nuclear Pharmacies in the United States

Alabama (1)

Nuclear Pharmacy, Inc.
1028 B 23rd St. South
Birmingham, AL 35205

Alaska (0)

None

Arizona (2)

Nuclear Pharmacy, Inc.
4228 E. Speedway Blvd.
Tucson, AZ 85712

Nuclear Pharmacy, Inc.
2612 North 7th St.
Phoenix, AZ 85006

Arkansas (0)

None

California (11)

Rad Pharm
637 S. Lucas St.
5th Floor
Los Angeles, CA 90017

Rad Pharm
Santa Clara Valley Medical Center
751 South Bascom Ave.
San Jose, CA 95128

Rad Pharm
2330 Clay St.
Stern Bldg. Rm. 310
San Francisco, CA

Nuclear Pharmacy, Inc.
1300 N. Fresno St.
Suite 201B
Fresno, CA 93703

Nuclear Pharmacy, Inc.
828 Mahler Rd.
Burlingame, CA 94010

Nuclear Pharmacy, Inc.
401 29th St.
Oakland, CA 94609

Nuclear Pharmacy, Inc.
2511 West Las Palmas
Unit W
Anaheim, CA 92801

Nuclear Pharmacy, Inc.
16140 Runnymede St.
Van Nuys, CA 91406

Nuclear Pharmacy of California, Inc.
3939 First Ave.
San Diego, CA 92103

Radiopharmacy
LAC-USC Medical Center
1200 N. State ST.
Los Angeles, CA 90033

Radiopharmacy
V.A. Hospital
3350 LaJolla Village Dr.
San Diego, CA 92161

Colorado (4)

Benedict Nuclear Pharmacy
1313 Washington Ave.
Golden, CO 80401

Benedict Nuclear Pharmacy
1216 Arapaho
Golden, CO

Mini-Dose Laboratories
1825 Emerson
Denver, CO 80218

Nuclear Pharmacy, Inc.
655 Broadway
Denver, CO 80203

Connecticut (2)

Central Radiopharmacy, Ltd.
Dept. of Nuclear Medicine
Univ. of Connecticut Health Center
Farmington, CT 06032

Central Radiopharmacy
Yale University
Health Services Center
New Haven, CT 06520

Delaware (0)

None

District of Columbia (2)

Pharmatopes, Inc.
4545 42nd St.
Washington, DC 20016

Western Diagnostics
Washington, DC

Florida (10)

Gulf Cost Nuclear
8826 North Davis Highway
Pensacola, FL

Pharmacon Nuclear, Inc.
8119 N.W. 33rd St.
Miami, FL 33122

Nuclear Pharmacy Inc.
5810 Miami Lakes Dr.
Building A
Miami Lakes, FL 33014

Nuclear Pharmacy, Inc.
60 W. Columbia
Suite 1B
Orlando, FL 32806

Nuclear Pharmacy, Inc.
1 Davis Blvd.
Suite B1
Tampa, FL 33606

Nuclear Pharmacy, Inc.
1240 N. Tamiami Trail
North Fort Meyers, FL 33903

Nuclear Pharmacy, Inc.
Sunrise Professional Center
5975 W. Sunrise Blvd.
Suite 202
Sunrise, FL 33313

Nuclear Pharmacy, Inc.
8670 49th St.
North Pinellas Park, FL 33585

Nuclear Pharmacy, Inc.
353 1/2 W. 8th St.
Jacksonville, FL 32206

Pharmatopes
7501 N.W. 66th St.
Miami, FL 33166

Georgia (3)

Nuclear Medicine Pharmacy
1016 Virginia St.
Columbus, GA

Medimco
6667 Vernon Woods Dr.
Suite B14
Atlanta, GA 30328

Nuclear Pharmacy, Inc.
1639 Tulle Circle, NE
Suite 107
Atlanta, GA 30329

Hawaii (1)

Pacific Radiopharmacy, Ltd.
347 North Kuakini St.
Honolulu, HI 96817

Idaho (0)

None

Illinois (2)

Nuclear Pharmacy, Inc.
319 W. Ontario
Chicago, IL 60610

Pharmatopes
210 S. Desplaines
Chicago, IL 60606

Indiana (2)

Pharmatopes, Inc.
5660 Carto Drive, Suite 101
Indianapolis, IN 46226

Pharmatopes, Inc.
1101 Sheffield
Dyer, IN 46311

Iowa (1)

Radiopharmacy
University of Iowa Hospital
Newton Rd.
Iowa City, IA 52240

Kansas (1)

Radiopharmacy
University of Kansas Medical Center
39th St. and Rainbow Blvd.
Kansas City, KS 66103

Kentucky (3)

Nuclear Pharmacy, Inc.
832 South 6th St.
Louisville, KY 40203

Blue-Grass Nuclear
1800 Nicholasville Rd.
Lexington, KY

Radiopharmacy
V.A. Hospital
Lexington, KY 40507

Louisiana (2)

Texatope
3911 Tulane Ave.
New Orleans, LA 70119

McCright's Pharmacy
Physicians' Square
1534 Elizabeth
Shreveport, LA 71101

Maine (0)

None

Maryland (1)

Pharmatopes, Inc.
2066 York Rd.
Suite 5
Timonium, MD 21093

Massachusetts (0)

None

Michigan (3)

Pharmatopes, Inc.
25721 Coolidge
Oak Park, MI 48237

Pharmatopes, Inc.
1553 Kalamazoo, SE
Grand Rapids, MI 49505

Radiopharmacy
University of Michigan Hospital
1405 East Ann St.
Ann Arbor, MI 48104

Minnesota (2)

DMI Nuclear Pharmacy
2233 University Avenue
Room 220
St. Paul, MN 55114

University of Minnesota Nuclear Pharmacy
420 Delaware St.
Box 382, Mayo Memorial Bldg.
Minneapolis, MN

Mississippi (1)

Nuclear Pharmacy, Inc.
5225 Galaxy Dr.
Jackson, MS

Missouri (2)

Pharmaco Nuclear, Inc.
1734 E 63rd St.
Kansas City, MO 64110

Pharmaco Nuclear, Inc.
100 N. Euclid Ave.
St. Louis, MO

Montana (0)

None

Nebraska (0)

None

Nevada (1)

Nuclear Pharmacy, Inc.
1325 A Vegas Valley Drive
Las Vegas, NV 89109

New Hampshire (0)

None

New Jersey (1)

Pharmatopes
225 Belleville Ave.
Bloomfield, NJ 07003

New Mexico (2)

Nuclear Pharmacy, Inc.
3240 Juan Tabo, NE
Building D
Albuquerque, NM 87111

Radiopharmacy
College of Pharmacy
The University of New Mexico
Albuquerque, NM 87131

New York (2)

Pharmatopes, Inc.
191 Herricks Rd.
Garden City Park, NY 11040

Central Radiopharmacy
Dept. of Nuclear Medicinie
Roswell Park Memorial Institute
State University of New York
666 Elm St.
Buffalo, NY 14203

North Carolina (3)

Duke University
Durham, NC

North Carolina Memorial Hospital
Chapel Hill, NC

Baptist Hospital
Winston-Salem, NC

North Dakota (1)

DMI Nuclear Pharmacy
Fargo, ND 58102

Ohio (7)

Pharmaco Nuclear, Inc.
10900 Carnegie Ave. Suite 308
Cleveland, OH 44106

Pharmatopes, Inc.
2719 Manchester Rd.
Akron, OH 44319

Pharmatopes, Inc.
4172 Crossgate Square
Blue Ash, OH 45236

Pharmatopes, Inc.
300 Forest Ave.
Dayton, OH 45405

Pharmatopes, Inc.
2208 W. Central
Toledo, OH 43600

Pharmatopes, Inc.
1100 Rarig Rd. Unit L
Columbus, OH 43219

Radiopharmacy
University of Cincinnati Medical Center
234 Goodman St.
Cincinnati, OH 45267

Oklahoma (2)

University of Oklahoma
Oklahoma City, OK

Pharmatopes
7446 E. 42nd Place
Tulsa, OK

Oregon (1)

Pharma Med Nuclear (The)
519 NW 21st Ave.
Portland, OR 97209

Pennsylvania (4)

Nuclear Pharmacy, Inc.
7446 Derry St.
Harrisburg, PA

Nuclear Pharmacy, Inc.
31 2nd North
Philadelphia, PA 19106

Pharmaco Nuclear
3402 Butler
Pittsburgh, PA

Radiopharmacy
Presbyterian University Hospital
NMD-4th Floor
230 Lothrop St.
Pittsburgh, PA 15253

Puerto Rico (0)

None

Rhode Island (0)

None

South Carolina (1)

Medical University of South Carolina
Charleston, SC

South Dakota (0)

None

Tennessee (3)

Nuclear Pharmacy, Inc.
1750 Madison Ave.
Suite B-50
Memphis, TN 38104

Nuclear Pharmacy, Inc.
210 25th Ave. North
Suite 131
Nashville, TN 37203

Nuclear Pharmacy, Inc.
2916 Tazewell Pike
Knoxville, TN 37918

Texas (7)

Nuclear Pharmacy, Inc.
4314 Medical Parkway
Suite 3
Austin, TX 78756

Nuclear Pharmacy, Inc.
1810 Murchison Dr.
Suite 205
El Paso, TX 79902

Nuclear Pharmacy, Inc.
2030 Century Center Blvd.
Suite 14
Irving, TX 75062

Nuclear Pharmacy, Inc.
2420 Quaker Avenue
Suite 203
Lubbock, TX 79410

Nuclear Pharmacy, Inc.
3701 Airport Freeway
Suite 101
Fort Worth, TX 76111

Nuclear Pharmacy, Inc.
6101 Southwest Freeway
Suite 125
Houston, TX 77057

Nuclear Pharmacy, Inc.
7342 Oak Manor Bldg. B-130
San Antonio, TX 78229

Utah (1)

Intermountain Radiopharmacy
University of Utah Medical Center
Salt Lake City, UT 84132

Vermont (0)

None

Virginia (2)

Pharmatopes, Inc.
413 W. Grace St.
Richmond, VA 23221

Pharmatopes, Inc.
85 S. Witchduck Rd.
Virginia Beach, VA 23462

Washington (1)

Northwest Radiopharmaceutical Services, Inc.
1305 1/2 E. Jefferson St.
Seattle, WA 98122

West Virginia (1)

Charleston Area Medical Center
3200 MacCorkle Ave.
Charleston, WV 25304

Wisconsin (1)

Nuclear Pharmacy, Inc.
933 North Mayfair Rd.
Suite 307
Wauwatosa, WS 53226

Wyoming (0)

None

APPENDIX C.

PERTINENT LITERATURE

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